SEVENTH CONFERENCE ON THE MATHEMATICS OF OPERATIONS RESEARCH & SYSTEMS THEORY

MB ST MB ST MB ST MB ST MB ST

BENELUX MEETING ON SYSTEM & CONTROL THEORY 1982

JANUARY 13-15, 1982

CONFERENCE CENTER "DE BLIJE WERELT"
LUNTEREN, THE NETHERLANDS

Dutch Research Community in the
Mathematics of Operations Research and Systems Theory

Dutch Research Community in the
Engineering of System and Control Theory

Mathematisch Centrum, Amsterdam

SEVENTH CONFERENCE ON THE MATHEMATICS OF OPERATIONS RESEARCH AND SYSTEMS THEORY

including the BENELUX MEETING ON SYSTEM AND CONTROL THEORY 1982

January 13-15, 1982
Conference Center "De Blije Werelt", Westhofflaan 2, Lunteren, The Netherlands

Invited Speakers

P. Franken	(Berlin)	: Queueing and Reliability
D. Gale	(Berkeley)	: Mathematical Programming
R.E. Kalman	(Zürich,Gainesville)	: Realization and Identification Theory
M.W. Padberg	(Louvain-la-Neuve)	: Combinatorial Optimization
W. Whitt	(Holmdel)	: Networks of Queues
P.C. Young	(Lancaster)	: System Identification

Minicourse

M.L.J. Hautus (Eindhoven)
P. van Dooren (Brussels)
: Synthesis of Multivariable Control Systems: a Geometric Approach

Contributed Short Lectures

by thirteen Benelux researchers in system and control theory.

Program: see back cover.

Questionnaire: see last page.

Sponsors

Dutch Research Community in the Mathematics of Operations Research and Systems Theory
Dutch Research Community in the Engineering of System and Control Theory
Belgian researchers in systems and control theory
Dutch Mathematical Society
Dutch Society for Operations Research
Mathematisch Centrum, Amsterdam

Organizers

J.K. Lenstra	(Mathematisch Centrum, Amsterdam)
J.H. van Schuppen	(Mathematisch Centrum, Amsterdam)
M.R. Roquas	(Mathematisch Centrum, Amsterdam)
R.K. Boel	(University of Ghent, Belgium)

Participants

D. Aeyels	University of Ghent
S.M. Baas	University of Technology, Enschede
R.A.J. Badoux	IWIS-TNO, The Hague
A.W.P. Bakkers	University of Technology, Enschede
G. Bastin	Catholic University, Louvain-la-Neuve
R. Bemelmans	University of Technology, Eindhoven
J.F. Benders	University of Technology, Eindhoven
J.P.C. Blanc	University of Utrecht
H.A.P. Blom	NLR, Amsterdam
R.K. Boel	University of Ghent
O.H. Bosgra	Agricultural University, Wageningen
O.J. Boxma	University of Utrecht
P.C. Breedveld	University of Technology, Enschede
J.C.P. Bus	Mathematisch Centrum, Amsterdam
F.M. Callier	University of Namur
J.W. Cohen	University of Utrecht
F. Colonius	University of Bremen
R.F. Curtain	University of Groningen
A.A.H. Damen	University of Technology, Eindhoven
J.L. de Jong	University of Technology, Eindhoven
R. Dekker	University of Leyden
R.M. Dekkers	University of Technology, Delft
A.G. de Kok	Free University, Amsterdam
W.L. de Koning	University of Technology, Delft
G. de Leve	University of Amsterdam/Mathematisch Centrum
H. de Meyer	Bayer, Antwerp
J.H. de Vlieger	University of Technology, Delft
B. Dorhout	University of Technology, Enschede
T.S.H. Driessen	Catholic University, Nijmegen
F. Eising	University of Technology, Eindhoven
J.J.M. Evers	University of Technology, Enschede
S. Geldof	IWIS-TNO, The Hague
M. Gevers	Catholic University, Louvain-la-Neuve
A.K. Hajdasinski	University of Technology, Eindhoven
M.L.J. Hautus	University of Technology, Eindhoven
A.W. Heemink	Rijkswaterstaat, Rijswijk

R.A. Hirschfeld	University of Antwerp
A. Hordijk	University of Leyden
C.E. Hubaut	Free University of Brussels
P.H.M. Janssen	University of Technology, Delft
A. Johnson	University of Technology, Delft
R. Jonker	University of Amsterdam
L.C.M. Kallenberg	University of Leyden
A.J.M. Kester	Mathematisch Centrum, Amsterdam
G. Kindervater	University of Amsterdam
W.K. Klein Haneveld	University of Groningen
G. Koch	University of Technology, Enschede
P. Koman	University of Technology, Enschede
J. Kriens	Catholic University, Tilburg
A.H. Kuipers	IWECO-TNO, Delft
H. Kwakernaak	University of Technology, Enschede
B.J. Lageweg	Mathematisch Centrum, Amsterdam
J.K. Lenstra	Mathematisch Centrum, Amsterdam
F.A. Lootsma	University of Technology, Delft
L.E. Meester	University of Technology, Delft
B.R. Meijboom	University of Technology, Eindhoven
T.C.A. Mensch	University of Technology, Delft
M.D. Merbis	Catholic University, Tilburg
J.A.J. Metz	University of Leyden
G. Moek	NLR, Amsterdam
J.R. Moll	Agricultural University, Wageningen
M. Moraal	University of Technology, Enschede
T.S. Ng	Catholic University, Louvain-la-Neuve
H. Nijmeijer	Mathematisch Centrum, Amsterdam
E. Noldus	University of Ghent
G.J. Olsder	University of Technology, Enschede
P.W. Otter	University of Groningen
M.H.C. Paardekooper	Catholic University, Tilburg
G. Papavassilopoulos	University of Southern California, Los Angeles
H.N.J. Poulisse	Catholic University, Nijmegen
A. Prékopa	Hungarian Academy of Sciences, Budapest
H. Rieuwerts	University of Technology, Delft
P.B.M. Roes	University of Technology, Delft
A. Schornagel	Mathematisch Centrum, Amsterdam

F.C. Schoute	Philips, Hilversum
P.A. Slats	IWIS-TNO, The Hague
I.H. Smit	Free University, Amsterdam
P.J.C. Spreij	University of Technology, Enschede
J. Staar	Catholic University, Leuven
R.C.W. Strijbos	University of Technology, Enschede
D. Tempelaar	University of Groningen
A.P. Terpstra	NLR, Emmeloord
H.C. Tijms	Free University, Amsterdam
S.H. Tijs	Catholic University, Nijmegen
H. Trentelman	University of Groningen
A.J. Udink ten Cate	Agricultural University, Wageningen
A. van Buuren	University of Technology, Eindhoven
E.E.C. van Damme	University of Technology, Eindhoven
A.J.W. van den Boom	University of Technology, Eindhoven
J.D. van der Bij	University of Technology, Eindhoven
F.A. van der Duyn Schouten	Free University, Amsterdam
A.J. van der Schaft	University of Groningen
J. van der Wal	University of Technology, Eindhoven
J. Vandewalle	Catholic University, Leuven
H. van de Water	University of Groningen
N. van Dijk	University of Leyden
P. van Dooren	Philips, Brussels
J.B.M. van Doremalen	University of Technology, Eindhoven
M.H. van Hoorn	Free University, Amsterdam
J.Th. van Lieshout	Catholic University, Tilburg
H. van Maaren	University of Technology, Enschede
J.J. van Rotterdam	KIWA, Rijswijk
J.H. van Schuppen	Mathematisch Centrum, Amsterdam
A.C.M. van Swieten	Fokker, Schiphol
G.A. van Zee	Agricultural University, Wageningen
H.B. Verbruggen	University of Technology, Delft
P.P. Wakker	University of Leyden
M.R. Weinberger	ESTEC-ESA, Noordwijk
J. Wessels	University of Technology, Eindhoven
J.C. Willems	University of Groningen
J.L. Willems	University of Ghent
W.H.M. Zijm	University of Amsterdam

OPTIMAL FILTERING OF DIFFUSIONS WITH BOUNDARY

R. Boel
M. Kohlmann

Laboratory for
Theoretical Electricity
University of Ghent
Grote Steenweg Noord 2
9710 Ghent (Zwijnaarde)
Belgium

In this talk a general model will be given for the problem of estimating the rate of an observed point process, when this rate is modeled as a diffusion process in the quadrant R_+^n . The boundary conditions will be emphasized. This is important for the control of a queue in a large network. Consider the general model :

$$dX_t = a(X_t)dt + b(X_t)dW_t + \sum_{i=1}^{n} \alpha_i(X_t)d\ell_t^i + \sum_{i=1}^{n} \beta_i(X_t)d\tilde{W}^i_{\ell_t^i}$$

where a and b model represent drift and diffusion inside R_+^n , α_i and β_i the average reflection and randomness in the reflection at the boundary plane $X_t^i = 0$; the boundary dynamics moves at the time scale ℓ_t^i , the local time on this boundary.

It is easy to determine $\mathcal{A}^*$, the forward operator and its domain $\mathcal{D}(\mathcal{A}^*)$. $\mathcal{D}(\mathcal{A}^*)$ expresses the boundary conditions of this partial differential operator $\mathcal{A}^*$. The observations form a point process with rate $\lambda(X_t)$. One then proves a Zakaï equation for an unnormalized conditional density q(t,x)

$$d_t q(t,x) = \mathcal{A}^* q(t,x) + \left(\frac{\lambda(x)}{\lambda_o} - 1\right)q(t,x)(dY_t - \lambda_o dt) \quad \text{with } q \in \mathcal{D}(\mathcal{A}^*)$$

Attemps at explicit solutions for the one-dimensional case will be reported later. These are based on a recent report of Beneš, using the integrated form of the Kallianpur-Striebel formula.

Reference

R. Boel and M. Kohlmann: Optimal control of diffusions with boundaries, in preparation.

THE TRACKING AND DISTURBANCE REJECTION PROBLEM FOR DISTRIBUTED-PARAMETER SYSTEMS

F.M. Callier

Department of Mathematics
Facultés Universitaires de Namur
Rempart de la Vierge 8
B-5000 Namur
Belgium

We study the servomechanism problem for a linear time-invariant multivariable plant, -signal- and disturbance generator, given by transfer matrices with elements in the convolution system transfer function algebra $\hat{\mathcal{B}}$ recently developed by Callier and Desoer. The necessary and sufficient structure of the feedback-loop compensator is established : an internal model reflecting the signal- and disturbance dynamics cascaded with a stabilizer of the loop.

References

[1] P.M.G. Ferreira and F.M. Callier, "The Tracking and Disturbance Rejection Problem for Distributed-Parameter Systems", IEEE Transactions on Automatic Control, to appear.

[2] F.M. Callier and C.A. Desoer, "Stabilization, Tracking and Disturbance Rejection in Multivariable Convolution Systems", Annales Soc. Scientifique de Bruxelles, T. 94, I, pp. 7-51 (1980).

COMPENSATORS FOR PARABOLIC DISTRIBUTED PARAMETER SYSTEMS

R.F. Curtain

Mathematical Institute
University of Groningen
P.O. Box 800
9700 AV Groningen

Recently, J.M. Schumacher in [1], has developed a theory for finite dimensional compensators for a class of infinite dimensional systems, including parabolic distributed systems. Essential assumptions were that the observations and control inputs were of bounded type. In an attempt to obtain results for unbounded inputs and observations, I used another scheme for the compensators, which in fact is much simpler than that used by J.M. Schumacher and reduces the computation considerably.
A numerical study for this latter scheme and the relationship between gains, the compensator order and degree of stability is being carried out by H. Bontsema for his 'afstudeer'research project. His interim results will be reported on and at the same time theoretical results on the case of unbounded inputs and obervations will be discussed.

Reference

[1] J.M. Schumacher, Dynamic Feedback in Time- and Infinite Dimensional Linear Systems, Doctoral Dissertation V.U., 1981.

A CAUTIOUS CONTROL ALGORITHM FOR STOCHASTIC CONTROL SYSTEMS WITH ADDITIONAL CONTROL CONSTRAINTS

J.H. de Vlieger

Department of
Electrical Engineering
Control Laboratory
University of Technology
Mekelweg 4
2628 CD Delft

The concept of the Deterministic Time-Optimal Control algorithm (D.T.O.C.), presented in [1], has been extended to stochastic systems with parameter and state uncertainty. The D.T.O.C. problem for discrete systems with boundary constraints on the control and state variables has been solved by means of linear programming techniques. In-line applications are possible, since linear programming allows an efficient computation of the control sequence. The D.T.O.C. algorithm belongs to the open-loop feedback class, i.e. an optimal control sequence is recalculated each sampling period, using measurements of the output variables, and parameter and state estimations. In [1] the certainty equivalence property has been used in order to apply the D.T.O.C. algorithm to stochastic control problems. However, enforcement of this property does not guarantee the desired performance. Especially in the case of time-optimal control one has to be cautious of large values of the control variables, which have been based upon incorrect a priori knowledge of the parameters. The optimal control strategy for stochastic systems yields control decisions which are cautious with regard to the uncertainty in the system and which probe the system for estimation purposes in order to decrease the uncertainty. Mainly because of mathematical difficulties it is hardly possible to derive optimal (dual) control algorithms. Several suboptimal algorithms have lost the probing property and, these are referred to as cautious control algorithms [2]. By making some assumptions a Cautious Time-Optimal Control algorithm, which is quite similar to the D.T.O.C. algorithm, will be derived. This algorithm does not have the disadvantage of the deterministic design of the D.T.O.C. algorithm and is cautious with respect to the parameter and state uncertainty of the system. Because of the open-loop form of the algorithm boundary constraints on the input variables can be added. Comparisons between the C.T.O.C algorithm and the D.T.O.C. algorithm will be presented.

References

[1] J.H. de Vlieger, H.B. Verbruggen, P.M. Bruijn, "An In-line Time-Optimal Algorithm for Digital Computer Control", Proc. of the 2nd IFAC/IFIP Symposium on Software in Computer Control, Prague, Czechoslovakia, 1979.

[2] Wittenmark B., "Stochastic Adaptive Control: a Survey", Int. J. Control, 21, 1975, p. 705.

ON THE POINT PROCESS APPROACH IN QUEUEING AND RELIABILITY

P. Franken

Department of Mathematics
Humboldt University
1086 Berlin
German Democratic Republic

The general theory of point processes is very useful in investigating queueing models in which there may be dependence among interarrival and service times. The purpose of the paper is to present some basic ideas of the point process approach to stationary stochastic systems in queueing, reliability and related topics.

We start with a brief survey of notions and results from the theory of point processes useful in the following and discuss different models of a stationary complete arrival process. The key point here is the equivalence between stationary marked point processes and suitable chosen stationary sequences. It is shown that the notion of processes with an embedded point process is of great importance in modelling of stochastic systems in steady state.

We discuss conditions ensuring the uniquely determined statistical equilibrium of a considered queueing system with a stationary complete arrival process and define in rigorous way time-,arrival- and departure-stationary queueing processes.

The emphasis is on deriving several relationships between the time-, arrival- and departure-stationary distributions, such as Little-type formulas, relationships between virtual and actual waiting time and queue length, discussion of busy cycles. These relationships lead in some cases to exact formulas or estimations for important queueing and reliability characteristics.

References

K. Arndt and P. Franken, Construction of a class of stationary processes with applications in reliability, Zastos. Mat. 16 (1979) 379-393

A. A. Borovkov, Asymptotic Methods in Queueing Theory (in Russian) (Nauka, Moscow, 1980)

A. Brandt and B. Lisek, On continuity of G/GI/m queues. Preprint 5/81, Dept. Mathematics, Humboldt-University, Berlin (1981). To appear in MOS, Ser. Statistics

J. W. Cohen, On Regenerative Processes in Queueing Theory. Lect. Notes in Econ. Math. Syst. 121 (Springer-Verlag, Berlin/Heidelberg/New York, 1976).

R. L. Disney and P. Franken, Further comments on some queueing inequalities, Tech. Rept., Dept. IEOR, VPI & SU, Blacksburg, Virginia, (1981). (Submitted to Mgt. Sc.)

P. Franken, D. König, U. Arndt and V. Schmidt, Queues and Point Processes (Akademie-Verlag, Berlin and Wiley, New York, 1981)

P. Franken and B. Lisek, On Wald's identity for dependent variables, Preprint 11/80, Dept. Mathematics, Humboldt-University, Berlin (1980) (To appear in Z. Wahrscheinlichkeitstheorie verw. Geb.).

P. Franken and A. Streller, Reliability analysis of complex repairable systems by means of marked point processes, J. Appl. Prob. 17 (1980) 154-167

D. König and V. Schmidt, Stochastic inequalities between customer-stationary and time-stationary characteristics of queueing systems with point processes, J. Appl. Prob. 17(1980) 768-777

M. Miyazawa, A formal approach to queueing processes in the steady state and their applications, J.Appl.Prob.16(1979)332-346.

S. C. Port and C. J. Stone, Infinite particle systems, Trans. Am. Math. Soc. 178(1973) 307-340.

A. Streller, On stochastic processes with an embedded marked point process, Preprint 10/80, Dept. Mathematics, Humboldt-University, Berlin (1980). To appear in MOS, Ser. Statistics

A. Streller, A generalization of cumulative processes, Elektron. Informationsverarb. Kybernetik, 16(1980) 8/9, 449-460.

K.-D. Wirth, On relations between stationary distributions in queues with batch arrivals and in some feedback queues, Preprint 6/81, Dept. of Mathematics, Humboldt-University, Berlin (1981).

OPTIMIZATION METHODS FOR SOLVING NON-OPTIMIZATION PROBLEMS

D. Gale

University of California
Berkeley, CA 94720
U.S.A.

CEREMADE
Université de Paris-Dauphine
Paris
France

One of the basic techniques of mathematical analysis is the so called variational method in which one proves the existence of an object with certain properties by solving a maximum or minimum problem. We give several examples of this, where the optimization is in the area of mathematical programming and is applied to economic equilibrium, pari-mutuel betting and problems of fair division.

References

D. Gale, "The Theory of Linear Economic Models". Mc Graw-Hill, New York, 1960, pp. 100-163.

E. Eisenberg and D. Gale, "Concensus of Subjective Probabilities: The Pari-Mutual Method". Annals of Math. Stat. 30, 1959.

D. Gale and J. Sobel, "Fair Division of a Random Harvest: The Finite Case". General Equilibrium, Growth and Trade. Academic Press, 1979, pp. 193-195.

CHOICE OF INVESTMENT AND CONTINUOUS TIME MATHEMATICAL PROGRAMMING

D. Gale

University of California
Berkeley, CA 94720
U.S.A.

CEREMADE
Université de Paris-Dauphine
Paris
France

We consider a production model in which output can be produced from labor combined with machines of various types. More efficient machines are more costly to build. The problem is to decide which machines to build at which time in order to maximize a discounted integral of utility. Using duality methods one obtains some interesting and, in some cases, surprising qualitative results.

References

R. Bellman, "Dynamic Programming". Princeton University Press, Princeton, N.J., 1957, pp. 105-109.

M. Hanson, "A Class of Continuous Convex Programming Problems". Journ. of Math. Analysis and Applications, 28.1, 1969.

W. Tyndall, "A Duality Theorem for a Class of Continuous Linear Programming Problems". SIAM Journal of Applied Math., 13.3, 1965.

SOME PROPERTIES OF MULTIVARIABLE STATIONARY STOCHASTIC FEEDBACK PROCESSES

M. Gevers

Bâtiment Maxwell
Louvain University
1348 Louvain-la-Neuve
Belgium

We consider stationary stochastic discrete-time vector processes made up of two vector component processes y and u, and such that the joint (y,u) process has a rational spectral density matrix $\phi_{yu}(z)$. The processes y and u can, for example, be the outputs and inputs of a stable constant linear closed loop system ; on the other hand it is often natural (e.g. in econometrics) to split up a stationary vector random process z into component vectors y and u, and to examine the closed-loop relations between y and u.

Such jointly stationary processes can be represented by a white noise driven transfer function model, and (in most cases) by a closed-loop model. We present a number of new results on the connections between these two representations, and on their properties : minimal degree condition, uniqueness, continuity and invertibility of the spectral factorization of $\phi_{yu}(z)$; stability and identifiability of the closed loop model for (y,u); detection of feedback from y to u.

References

M. Gevers, B.D.O. Anderson, "Representation of jointly stationary stochastic processes", Int. J. Control, vol. 33, N°5, 1981, pp. 777-809

M. Gevers, B.D.O. Anderson, "New results of stationary stochastic feedback processes", Proc. 8th IFAC World Congress, Kyoto, Japan, 1981, vol.VI, pp. 143-148

B.D.O. Anderson, M. Gevers, "Identifiability of linear stochastic systems operating under linear feedback", Automatica, March 1982.

MINICOURSE

SYNTHESIS OF MULTIVARIABLE CONTROL SYSTEMS: A GEOMETRIC APPROACH

M.L.J. Hautus

Department of Mathematics
University of Technology
P.O. Box 513
5600 MB Eindhoven

I. Basic concepts and results

One of major applications of "geometric system theory" is the solution of the regulator problem. In the classical theory the *stabilization problem* was solved, that is the problem of constructing a compensator such that the resulting system is stable. The more recent theory deals with a generalization of the problem in two ways:

1) it is assumed that exogenuous signals enter the plant
2) the objective is to stabilize not the whole state variable, but only a certain output variable.

In this situation one speaks of *the regulator problem*. In this part of the course, first a general formulation of the problem is given and also the somewhat easier problem of *disturbance decoupling problem* is discussed. This is the problem of finding a compensator which is such that in the resulting system, the output is independent of the exogenuous input (noise, disturbance). This problem can be formulated with or without stability requirements.

The main part of the lecture will consist of an introduction and a discussion of the fundamental concepts of the theory: controlled invariant subspaces, inner and out stabilizable subspaces. Also, the basic theory will be applied for solving the regulator problem and the disturbance decoupling problem with state feedback (that is, under the assumption that the entire state variable is available for measurement).

III. The regulator problem

If not the state variable but only an output is measured, one needs observers to estimate the state and in order to investigate the existence of such observers, concepts are used "dual" to the concepts of controlled invariant, inner and outer stabilizable spaces are used. These dual concepts are called: conditional invariant, and outer and inner detectable spaces. The primal and dual concepts are combined in the notion of (C,A,B)-pairs introduced by J.M. Schumacher. It turns out that (C,A,B)-pairs are very convenient in deriving conditions for the existence of regulators as well as for their explicit construction.

References

W.M. Wonham, *Linear multivariable control: a geometric approach*, Springer-Verlag, New York, 1979.

J.M. Schumacher, *Dynamic feedback in finite- and infinite-dimensional linear systems*. Thesis, Vrije Universiteit, Amsterdam, 1981.

THE USE OF KALMAN-BUCY FILTERS IN FORCASTING THE WATERLEVELS IN THE DUTCH COASTAL AREA

A.W. Heemink

Dienst Informatieverwerking
Nijverheidsstraat 1
2280 HV Rijswijk (ZH)

In modelling the water movements in coastal areas it is a well-known fact that the various parameters which represent the influences of the physical phenomena on these movements have essentially a random character e.g. the variations in the sea level due to the changing weather conditions, the salt-fresh water ratio which may vary near a river mouth, the bottom friction which depends on the bottom profile which may also change in time, etc. Usually, in numerical calculations the velocities and water levels are calculated by inserting these parameters which are derived from field data as deterministic quantities in the used mathematical model. In addition the initial and boundery conditions have to be given by prescribing the water levels and/or water velocities. Also these conditions have to be derived from field data and contain a random component due to inaccuracies in the measurements. In this paper we derive a stochastic model by using the shallow water equations supplemented with equations for the random parameters, e.g. wind stress coefficient, friction coefficient, etc. By introducing system noise in these equations we take into account the uncertainties in this model. The field observations are inserted in a system of observation equations and are allowed also a certain measure of uncertainty by adding measurement noise. A discrete Kalman-Bucy filter is derived on the basis of this set of system equations and observation equations. The filter gives estimates of the waterlevel and watervelocity together with the above mentioned parameters. In this paper we give an application of a filter based on the one-dimensional non-linear shallow water equations. The two-dimensional effects are estimated by inserting in these equation additional terms containing space-dependent parameters which are estimated together with the other system variables and which are adapted automatically by the filter when the physical circumstances change, (rising of a storm surge, changing of the bottom profile, etc.). This filter is applied to field data gathered in the Dutch coastal area. It will be shown that the filter gives satisfactory results in forcasting the waterlevels both for stationary weather conditions and storm surge periods.

References

Arnold Heemink, "Een Kalman-filter voor het voorspellen van de waterhoogte in de mond van de Oosterschelde", Report DIV, 1981.

Andrew H. Jazwinski, "Stochastic processes and filtering theorie", Academic Press, New York and London, 1970.

J. J. Dronkers, "Tidal computations in rivers and coastal waters", North-Holland publishing company, Amsterdam, 1964.

MODEL BUILDING: IDENTIFICATION FROM EXACT AND FROM NOISY DATA

R.E. Kalman

Swiss Federal Institute
of Technology
Zürich
Switzerland

University of Florida
Gainesville, FL 32611
U.S.A.

The main theme of these lectures is realization of models from data. Of special interest is the question of the uniqueness (= unprejudicedness) of the resulting models.

Partial realizations and the so-called maximum entropy principle

The problem of realization from exact data is best approached via partial (= sequential) realization theory. While the results in this area are to some extent classical, important open problems remain when additional conditions are imposed on the realization, like positivity. We will show that in such cases the standard "application" of the maximum entropy principle leads to self-contradictory results; this has important implications on the general problem of time-series modeling, as, for example, in econometrics.

Reference: R. E. Kalman, "On partial realizations, transfer functions, and canonical forms", Acta Polytechnica Scandinavica, Mathematics and Computer Science Series No. 31, 1979, pages 9-32.

Identification of linear relations from noisy data

The classical approach to this problem (so-called simultaneous equation estimation) is subject to very serious objections; for example, none of the words "simultaneous", "equation", or "estimation" is used in the correct sense in the econometrics literature concerned with this problem. We shall show where the research effort (originally mainly due to R. FRISCH) had gone astray and what the modern results will eventually turn out to be. The problem is of considerably greater mathematical depth than has been heretofore widely supposed.

References: R. E. Kalman, "System-theoretic critique of dynamic economic models", International J. of Policy Analysis and Information Systems, 4 (1980) pages 3-22.

R. E. Kalman, "Identifiability and problems of model selection in econometrics", Proceedings of the 4th World Congress of the Econometric Society, 1980, Cambridge University Press.

R. E. Kalman, "System identification from noisy data", to appear in INTERNATIONAL SYMPOSIUM ON DYNAMICAL SYSTEMS, Gainesville, FL, February 1981.

DESIGN OF ROBUST CONTROL SYSTEMS

H. Kwakernaak

Department of
Applied Mathematics
Twente University
of Technology
P.O. Box 217
7500 AE Enschede

Some recent results concerning the design of robust control systems are described. These include first of all a sufficient condition for the existence of a (fixed) controller that stabilizes a family of linear time-invariant finite-dimensional plants. Secondly a number of stability criteria for perturbed closed-loop systems are discussed that may be used as a tool in the design of robust control systems.

References

H. Kwakernaak, "A condition for robust stabilizability". Memorandum Nr. 351, Department of Applied Mathematics, Twente University of Technology, September, 1981.

Gu Q.-T., H. Kwakernaak, "A stability robustness criterion and its application to control system design". Memorandum Nr. 352, Department of Applied Mathematics, Twente University of Technology, September, 1981.

NONLINEAR CONTROLLED INVARIANCE: A WORKED EXAMPLE

H. Nijmeijer

Mathematisch Centrum
Kruislaan 413
1098 SJ Amsterdam

During the last few years there has been a growing interest in the differential geometric approach to nonlinear systems theory. This approach is more or less a generalization of the topic of the minicourse of this conference. It turns out that the basic concepts of the geometric systems theory, like (A,B)-invariant subspaces and (C,A)-invariant subspaces, can be translated to nonlinear systems theory. The tools needed to do so come from a for engeneering rather unknown field of mathematics: differential geometry. Instead of introducing all the necessary backgrounds of differential geometry I will directly go to the study of a typical example from nonlinear control theory. This example - a controlled rigid body - will serve as an illustration of the Disturbance Decoupling Problem for nonlinear systems. A detailed account of this talk as well as further references on nonlinear (A,B)-invariance may be found in [1].

Reference

[1] Henk Nijmeijer & Arjan van der Schaft: Nonlinear controlled invariance: two worked examples, preprint.

DESIGN OF ROBUST STATE FEEDBACK LAWS

E. Noldus

Automatic Control Laboratory
University of Ghent
9710 Zwijnaarde
Belgium

Existence criteria and computational methods are presented for designing robust state feedback laws, preserving closed loop stability of multivariable systems with uncertain state or control matrices. The uncertainties are modelled as cone bounded time and state dependent nonlinearities. Using Liapunov's direct method exhaustive search methods for a stabilizing linear feedback controller are obtained : If there exist a stabilizing feedback law and a quadratic Liapunov function proving closed loop stability, then a solution is always found. The algorithms essentially amount to repeatedly solving a parameter dependent Riccati equation until the maximal solution becomes positive definite.

Problems dealing with the cases of systems with jointly uncertain state and control matrices, systems with output feedback and the design of robust dynamic controllers are presently under investigation.

References

P. Molander and J.C. Willems : Synthesis of state feedback control laws with a specified gain and phase margin. IEEE Trans. Auto. Control, 25, 5, 928-931 (1980)

E. Noldus : Design of robust state feedback laws. Submitted to : Int. J. Control.

COVERING, PACKING AND KNAPSACK PROBLEMS

M.W. Padberg

CORE
34 Voie du Roman Pays
Louvain-la-Neuve
Belgium

New York University
New York, NY 10006
U.S.A.

We survey some of the recent results that have been obtained in connection with covering, packing, and knapsack problems formulated as linear programming problems in zero-one variables.

Reference

M.W. Padberg (1979) Covering, packing and knapsack problems. *Ann. Discrete Math.* 4,265-287.

SOLVING LARGE-SCALE ZERO-ONE LINEAR PROGRAMMING PROBLEMS

M.W. Padberg

CORE
34 Voie du Roman Pays
Louvain-la-Neuve
Belgium

New York University
New York, NY 10006
U.S.A.

The management science and operations research literature abounds with problems which can be appropriately formulated using zero-one variables which have to satisfy certain linear constraints. It is generally assumed, however, that — while useful for the analysis of real-world problem situations — zero-one problems of large-scale are not amenable to solution by exact methods. This is partly so because the general zero-one problem with linear constraints and linear objective function is among the NP-complete or "hard" combinatorial optimization problems for which, to date, no technically good algorithms are available. In this paper we report the *solution to optimality* of ten large-scale zero-one linear programming problems. All problem data come from real-world industrial applications and are characterized by *sparse* constraint matrices with rational data. About half of the sample problems have no apparent special structure; the remainder show structural characteristics which are not exploited directly by our computational procedures. Our methodology produced — by today's standards — impressive computational results, in particular on sparse problems having no apparent special structure. The test problems were given to us from various sources within and outside of the IBM Corporation and, while we have no comparative data on previous solution attempts, most were originally considered not amenable to exact solution in economically feasible computation times. The computational results reported here contradict this sentiment and strongly confirm our hypothesis that a combination of problem preprocessing, cutting planes and clever branch-and-bound techniques permit the optimization of sparse large-scale zero-one linear programming problems, even when no apparent special structure is present, in reasonable computation times. Our results indicate that cutting-planes are an indispensable tool for the exact solution of this class of problem. To arrive at these conclusions, we designed an experimental computer system PIPX which uses the IBM linear programming system MPSX/370 and the IBM integer programming system MIP/370 as building blocks. The entire system is automatic and requires no manual intervention.

Reference

H. Crowder, E.L. Johnson, M.W. Padberg (1981) Solving large-scale zero-one linear programming problems. Research Report RC8888(#38963), IBM Thomas J. Watson Research Center, Yorktown Heights, NY.

A SYSTEMS APPROACH TO THE ANALYSIS OF SWITCHED CAPACITOR CIRCUITS

J. Vandewalle

ESAT Laboratory
Katholieke Universiteit Leuven
Kard. Mercierlaan 94
3030 Heverlee
Belgium

Because networks with capacitors, periodically controlled switches and op amps have allowed to make filters and signal processing systems on one chip, such networks have received much attention from IC companies. The analysis of such circuits is however not so simple and a great variety of approaches has been proposed, often with unnecessary restrictions. Our research has attempted to unify and generalize the approaches and bring it more in the realm of system theory. First those circuits can be considered as periodic time-varying linear systems [1]. Second if no resistances appear, and this is ideally the case, the system can be described with rational matrices and multivariable impulse responses between the different phases [2]. The derivations can be easily visualized in diagrams for the time and frequency domain. Our whole approach thereby puts all others into perspective. The key systemtheoretic results will be derived and the applications in a CAD program will be briefly mentioned.

References

[1] J. Rabaey, J. Vandewalle and H. De Man, "On the frequency domain analysis of switched capacitor networks including all parasitics", Proc. IEEE ISCAS Conference Chicago, pp. 868-871, May 1981.

[2] J. Vandewalle, H. De Man and J. Rabaey, "Time frequency and z-domain modified nodal analysis of switched capacitor networks", IEEE Trans. on Circuits and Systems, Vol. CAS-28, pp. 186-195, March 1981.

ON ADAPTIVE SSR-IDENTIFICATION WITH GUARANTEED SIGNAL-TO-NOISE RATIO

J. Staar

ESAT 01
Kard. Mercierlaan 94
3030 Heverlee
Belgium

From recent contacts in Japan [1], it has clearly appeared that (5x5) multivariable linear systems of degree up to 25 are no longer academic constructs, but real life objects for control system designers. We discuss the type of fundamental problems, that arise when systems of this complexity have to be (adaptively) identified, and we propose a solution based on the Minimal Signal to Noise Ratio principle [2].

We will describe the State Space Model identification procedure IIDENT. IIDENT is the first on line model tracking procedure for the identification of nonparametrized multivariable State Space Realizations, that is implementable on a standard microcomputer, even for relatively high model degrees (up to 15). The succes of the procedure is based on three ingredients: Tail Correction, Iterative Impulse Response Identification, and Iterative Realization.

A feasibility study showed the impressive efficiency of IIDENT: The complete adaptive on-line SSR identification of a 2x2 multivariable system of a degree up to 15 is easily executable on a standard micro-computer.

References

[1] K. Furuta (Tokyo Institute of Technology) : Personal communication

[2] J.Staar, J.Vandewalle and M. Wemans : "Realization of truncated impulse response sequences with prescribed uncertainty.", IFAC VIII World Congress Kyoto(Japan), Aug. 1981.

MINICOURSE

SYNTHESIS OF MULTIVARIABLE CONTROL SYSTEMS: A GEOMETRIC APPROACH

P. van Dooren

Philips Research Laboratories
Van Becelaerelaan 2
1170 Brussels
Belgium

II. Numerical algorithms

In this second part of the course we look at the computation of the geometrical concepts described above, from a numerical point of view.
We first brielfy survey the numerical background that is required for the analysis of the algorithms we discuss. Key words in this context are : numerical stability, conditioning, rank determination and orthogonal transformations. We show that, using these preliminary concepts, one derives "reliable" numerical algorithms for solving control problems such as disturbance rejection and various kinds of stabilization.
The main idea in our approach is to use an appropriate state-space transformation $\mathcal{T}$ such that the geometric space we are interested in, is trivially displayed. In the new coordinate system, the space will e.g. be spanned by a number of unit vectors. The corresponding feedback problem is thereby reduced to merely solving a set of linear equation.
The availability of basic software for the solution of the above problems is also discussed.

References

Van Dooren P., "The generalized eigenstructure problem in linear system theory", IEEE Trans. Aut. Contr., Vol. AC-26, pp. 111-129, Feb. 1981.

Minimis G., Paige C.C., "An algorithm for pole assignment of time invariant linear systems", to appear in Int. J. Control.

VALIDATION OF PREDICTION ERROR IDENTIFICATION RESULTS BY MULTIVARIABLE CONTROL IMPLEMENTATION

G.A. van Zee

Department of
Physics and Meteorology
University of Agriculture
Duivendaal 1
6701 AP Wageningen

This paper discusses the validation of models obtained by prediction error identification of an 8-input, 8-output pilot scale heat exchanging process. Approximating models, obtained from closed-loop experiments, have been used to design multivariable feedback control laws for the process. The in-line digital implementations of these control laws on the actual process have been evaluated by comparing the actual closed-loop behaviour with model predictions. The results have been used as a measure for model accuracy and demonstrate certain deficiences of the usual one-step ahead prediction error identification criterion. It appears that the accuracy of the initial model, obtained by stochastic realization, deteriorates when its parameters are optimized with respect to the criterion. It is shown that this problem is caused by the low frequency model errors which are important when considering the suitability of the models for the design of control systems incorporating integral feedback, but which are not sufficiently reduced by the considered prediction error approach. A modified criterion giving more weight to low frequency model errors is shown to yield models with significantly improved actual closed-loop behaviour.

References

Anderson, B.D.O., J.B.Moore, R.M.Hawkes (1978), Model approximations via prediction error identification, Automatica, 14, 615-622.

Ljung, L., A.J.M.Van Overbeek (1978),Validation of approximate models obtained from prediction error identification, Proc. 7th Triennial World Congress IFAC Helsinki 1978, Pergamon Press, Oxford, 1899-1906.

Van Zee, G.A. (1981), System identification for multivariable control, Thesis, Delft University of Technology, The Netherlands.

APPROXIMATIONS FOR NETWORKS OF QUEUES

W. Whitt

Bell Laboratories
Holmdel, NJ 07733
U.S.A.

Complex systems such as computers and communication networks require complex models such as networks of queues, which in turn require simulation or approximation. A simple approximation method for networks of queues will be discussed. The first step is to work with simple summary descriptions of each stochastic process involving two or three parameters. The second step is to have an elementary calculus for transforming the parameters to describe the basic operations of composition (superposition), decomposition (splitting), flow through a queue, overflow, etc. For this purpose, it is convenient to use renewal processes as approximating point processes and the moments of the renewal interval as the basic parameters. The third step is to apply simple approximations for single queuing stations based on the parameters. Once the parameters have been determined, each queuing station can be analyzed in isolation.

In this context, a key question is: How should we approximate a point process by a renewal process? This can be done in two steps: First, properties of the point process are used to specify a few moments of the interval between renewals; then, if necessary, a convenient distribution can be fit to these moments. However, the renewal process or renewal-interval moments we get depend on the point process properties we use. Two different basic methods are suggested for specifying the moments of the renewal interval: The stationary-interval method equates the moments of the renewal interval with the moments of the stationary interval in the point process to be approximated. The asymptotic method, in an attempt to account for the dependence among successive intervals, determines the moments of the renewal interval by matching the asymptotic behavior of the moments of the sums of successive intervals. These two procedures were applied to approximate the superposition (merging) of point processes, and compared with the aid of computer simulation in the setting of a single-server queue with multiple renewal arrival processes. Both procedures have regions where they perform well, but also both have regions where they perform poorly. Much better than either procedure alone is a refined hybrid procedure developed by Albin. For a large class of $\Sigma G_i/G/1$ queues, the average error in the mean queue length for the hybird procedure was about 3 percent.

The basic approximation methods have also been applied to develop hybrids for the other operations arising in a general network of queues. Such approximation procedures are currently being tested. They yield simple algorithms for the classical Jackson networks of queues (the Markov case) modified to have non-Poisson arrival processes, multiple servers at each facility and nonexponential service-time distributions. It is possible to represent each network operation as a linear transformation, so that the algorithm simply consists of solving systems of linear equations.

References

I. Networks of Queues: Theory and Application

[1] Kelly, F. P. (1979) Reversibility and Stochastic Networks, John Wiley and Sons, New York.

[2] Kleinrock, L. (1976) Queuing Systems, Volume 2: Computer Applications, John Wiley and Sons, New York.

[3] Sauer, C. H. and Chandy, K. M. (1981) Computer Systems Performance Modeling, Prentice-Hall, Englewood Cliffs, New Jersey.

II. Approximations for GI/G/s Queues

[4] Boxma, O. J., Cohen, J. W. and Huffels, N. (1980) Approximations of the mean waiting time in an M/G/s queuing system. Operations Research, Vol. 27, pp. 1115-1127.

[5] Halfin, S. and Whitt, W. (1981) Heavy-traffic limits for queues with many exponential servers. Operations Research, Vol. 29, pp. 567-588.

[6] Tijms, H. C., Van Hoorn, M. H. and Federgruen, A. (1981) Approximations for the steady-state probabilities in the M/G/c queue. Advances in Applied Probability, Vol. 13, pp. 186-206.

III. Approximations for Point Processes and Networks of Queues

[7] Albin, S. L. (1981) Approximating Queues with Superposition Arrival Processes, Ph.D. dissertation, School of Engineering Science, Columbia University.

[8] Albin, S. L. (1982) On Poisson approximations for superposition arrival processes. Management Science, Vol. 28, to appear in February.

[9] Kosten, L. (1980) Approximate determination of congestion quantities by equivalent traffic methods, Delft Progress Report, Mathematics and Mathematical Engineering, Vol. 5, pp. 227-252.

[10] Kühn, P. (1979) Approximate analysis of general queuing networks by decomposition. IEEE Transactions on Communications, Vol. COM-27, pp. 113-126.

[11] Whitt, W. (1981) Approximating a point process by a renewal process: the view through a queue, an indirect approach. Management Science, Vol. 27, pp. 619-636.

[12] Whitt, W. (1982) Approximating a point process by a renewal process, I: two basic methods. Operations Research, Vol. 30, to appear in January - February.

MODELING AND REALIZATION OF SYSTEMS DEFINED DIRECTLY IN TERMS OF EXTERNAL VARIABLES

J.C. Willems

Mathematical Institute
University of Groningen
P.O. Box 800
9700 AV Groningen

The usual starting point for the axiomatization of systems is [1] to define a dynamical system as an input/output map or, in an input/state/output framework, in terms of a state transition and a read-out function. This approach has some disadvantages however, the most important one being that for many mathematical models encountered in the physical sciences, economics, etc., it is much more natural to view models as a compatibility relation linking external variables. An input/output model then appears as a particular representation which displays the causality structure. Our formal definition [2] thus is to take a *dynamical system* as a subset Σ_e of W^T, with $T \subset \mathbb{R}$ the time-axis and W the space in which the external variables take on their values. This definition will be motivated by means of examples and it will be argued that this offers the logical context in which to introduce such notions as time-invariance, linearity, time-reversibilty, autonomous systems, etc.

It is possible to define also dynamical systems in state space form in this context. With the notion of external behavior we are then naturally lead to the question of realization which consists in finding a state space representation of a system with a given external behavior. We will review the main ingredients of such a theory with particular emphasis on finite dimensional linear time-invariant systems where it is possible to prove that all minimal realizations of a given external behavior are equivalent and that a realization is minimal iff the supremal L_1-almost invariant output nulling subspace [3] is zero. We will also illustrate how differential systems are defined in this set-up and how this way one can conceptualize mechanical systems incorporating external forces in a Hamiltonian differential geometric framework, following the work in [4] (see also [5,6]).

References

[1] R.E. Kalman. P.L. Falb, and M. Arbib, *Topics in Mathematical System Theory*, McGraw-Hill, 1969.
[2] J.C. Willems, *Ricerche di Automatica*, Vol.10, No.2, pp. 71-106, 1979.
[3] J.C. Willems, *IEEE Tr. Automatic Control*, Vol.AC-26, pp. 235-252, 1981.
[4] A.J. van der Schaft, *Mathematical System Theory*, to appear.
[5] R.W. Brockett, *Geometric Control Theory*, pp. 1-46, Math. Sci. Press, 1977.
[6] A.J. van der Schaft, *Systems & Control Letters*, Vol.1, No.2, pp. 108-115, 1981.

RECURSIVE TIME-SERIES ANALYSIS

P.C. Young

Department of Environmental Sciences
University of Lancaster
Lancaster LA1 4YQ
England

Recursive parameter estimation adds a new dimension to time-series analysis allowing not only for the efficient on-line processing of time-series data but also for the possibility of identifying temporal change in the parameters of the time-series model. And yet, despite these obvious advantages, the potential user is often dissuaded from using recursive methods because of the confused and confusing literature on the subject. As Astrom and Eykhoff have said, recursive estimation is a "fiddlers paradise"; and while such fiddling is great fun for the researcher, it does little to help the practitioner in selecting a relevant algorithm in relation to his particular problem.

The present paper attempts to guide the potential user through this maze of methodology by discussing the advantages and disadvantages of different time-series models and their associated recursive methods of identification (the definition of model order or structure) and parameter estimation. It is shown that time-series models can be considered either as "errors-in-equations" or "errors-in-variables" representations and that, depending upon the nature of the problem at hand, the selection of an appropriate representation can have important repercussions on the subsequent analysis. Further, we see that concepts such as identification, consistency, asymptotic efficiency and robustness all need to be considered carefully in choosing a particular estimation algorithm.

The paper concludes that the errors-in-variables model has certain advantages in general day-to-day use, although the errors-in-equations alternative can be more useful in certain applications. It is also argued that the estimation of parameters in the most common errors-in-variables representation, namely the transfer function or Box-Jenkins model, can best be achieved by the use of either prediction error (PE) minimisation or the alternative optimal generalised equation error (OGEE) minimisation. Both approaches yield estimates with the same asymptotic properties of consistency and asymptotic efficiency, but the OGEE method yields instrumental variable (IV) algorithms that are more robust in practical application and seem, therefore, to have more attraction to the practitioner.

References

1. YOUNG, P.C. (1976) Some observations on instrumental variable methods of time-series analysis, *Int. Jnl. Control*, 23, 593-612.
2. YOUNG, P.C. and JAKEMAN, A.J. (1979-80) Refined instrumental variable methods of recursive time-series analysis, Parts I, II and III, *Int. Jnl. Control:* 29, 1-30; 29, 621-644; 31, 741-764.
3. YOUNG, P.C. (1979) Parameter estimation for continuous-time models - a survey, in R. Isermann (ed.) *Identification and System Parameter Estimation*, Pergamon Press: Oxford (also *Automatica*, 17, 23-39, 1981).

THE IDENTIFICATION AND ESTIMATION OF BADLY DEFINED SYSTEMS

P.C. Young

Department of Environmental Sciences
University of Lancaster
Lancaster LA1 4YQ
England

Environmental and socio-economic systems are not easy to analyse in mathematical terms because they tend to be rather badly defined from a scientific standpoint. This poor definition arises for two major reasons. First, there is often a basic ambiguity about the behavioural mechanisms; a situation where a number of possible explanations for the observed behaviour seem feasible, but where there exists little *a priori* evidence as to which of these explanations seems most plausible. Secondly, it is often difficult, if not impossible, to either conduct planned experiments or collect adequate quantities of *in situ* data during the "normal operation" of the system.

Faced with the dilemma of analysing such poorly defined systems, it is necessary for the analyst to develop systematic modelling procedures which recognise the basic difficulties and avoid some of the mistakes made by model builders in the past. This lecture outlines a particular approach to the modelling of badly defined systems which is consistent with the hypothetico-deductive procedures of the scientific method and can be considered within a Bayesian statistical framework. It exploits sophisticated methods of recursive time-series analysis (which are the embodiment of Bayesian analysis) to detect important nonlinear and non-stationary aspects of the observed behaviour and so define a model structure which is objective orientated, parametrically efficient and compatible with the identifiability of the model in relation to the available data. In this manner, the main impediments to the use of the model, either as a predictive device or for control and management, will often become more apparent and the possibility of its mis-use will be minimised.

References

1. YOUNG, P.C. (1978) A general theory of modeling for badly defined systems, in G.C. Vansteenkiste (ed.) *Modeling, Identification and Control in Environmental Systems,* North Holland, Amsterdam.

2. YOUNG, P.C. (1981) The validity and credibility of models for badly defined systems, to appear in M.B. Beck and G. van Straten (eds) *Uncertainty and Forecasting of Water Quality* IIASA/Pergamon: Oxford, (presented at Task Force Mtg. Int. Inst. Applied Syst. Anal. (IIASA), Vienna, 1980)

3. PRIESTLEY, M.B. (1980) State dependent models: a general approach to nonlinear time-series analysis, *Time Series Anal.,* 1, 47-72.

4. KALMAN, R.E. (1981) Identifiability and problems of model selection in econometrics, invited lecture, 4th World Congress of Econometric Society, Aix-en-Provence, 1980 (revised version 1981).

Questionnaire

The organizers of this conference have been informed that some participants *cannot* get financial support from their institute to visit the meeting. To provide the organizers with more information on this point, please fill out this questionnaire and return it to J.K. Lenstra or J.H. van Schuppen. The information will be treated confidentially.

1. Name (optional):

2. Institute:

3. The costs of participation in the Seventh Conference on the Mathematics of Operations Research and Systems Theory have been paid by:

	registration fee	travel cost
myself:	☐	☐
my institute:	☐	☐

4. Further remarks: