ACTIVITY REPORT '97

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General

Institute of Information Theory and Automation is a research institute of the Academy of Sciences of the Czech Republic. It is involved with basic research in systems, control, and information sciences.

This report gives an overview of our research activities in 1997. It is of course impossible to give a full account of the research results here. The results selected are divided into sections representing the seven research departments of the Institute. Each department is briefly introduced and its overall activity is described. The report is completed by a list of works published and/or accepted for publication.

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Academy of Sciences of the Czech Republic

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The Institute of Information Theory and Automation (ÚTIA) was established in 1959 as a merger of two academic laboratories: the Department of Information Theory of the Institute for Radio-engineering and Electronics and the Laboratory for Automation and Telemechanics.

ÚTIA has been involved with basic research in systems, control, and information sciences. In the 1960s it obtained significant results on the entropy of various sources and on the capacity of information channels with memory. An algebraic approach to control system design was developed during the 1970s which yielded many important results, among which is a parametrization of all stabilizing controllers. The main contributions of the 1980s include a Bayesian approach to self-tuning control, a theory of Rényi distances in probability spaces, and a method of mathematically modelling large-scale gas-distribution networks. Recent developments are in recursive nonlinear estimation and pattern recognition. Currently ÚTIA holds research grants from many domestic and foreign agencies.

The scientific library of ÚTIA contains 30.000 books and periodicals. The computational resources of ÚTIA include an SGI Power Challenge XL computer and a local area network of HP 720 workstations and personal computers. ÚTIA is the administrator of the Academy of Sciences network domain. In 1990, ÚTIA received a major grant from the Andrew W. Mellon Foundation, New York, to upgrade its facilities. During 1996 – 1997 the Institute completely reconstructed and extended its local area network.

ÚTIA publishes the scientific journal Kybernetika and is the seat of the Czech Society for Cybernetics and Informatics. It regularly organizes the Prague Conferences on Information Theory as well as other events sponsored by the International Federation of Automatic Control (IFAC), International Federation of Information Processing (IFIP), International Association of Pattern Recognition (IAPR) and the Institute of Electrical and Electronics Engineers(IEEE). In 1996 ÚTIA joined the European Research Consortium on Informatics and Mathematics (ERCIM).

ÚTIA has developed close research and teaching contacts with many academic and industrial institutions. It is affiliated with several institutions of higher education, including the Czech University of Technology and Charles University, and coordinates Central European Graduate School in Systems and Control Theory. It houses the Prague Technology Center, a joint research establishment with Honeywell, Inc. Close cooperation with the Terezín National Memorial and Terezín Initiative (Terezín was the location of a concentration camp and ghetto during WW-2) in the construction of prisoners' database resulted in the publication of Terezín Memorial Book – Vol I. and Vol. II.

The Institute organized the

- 7th World Congress of International Fuzzy Set Association, Prague 1997.
- Workshop on Statistical Techniques in Pattern Recognition, Prague 1997.

and participated in the organization of numerous other conferences.

Among others, the following events are under preparation:

- Prague Stochastics, Prague 1998.
- 3rd IEEE Workshop on Computer Intensive Methods in Control and Signal Processing, Prague 1998.

Contents

General 1

1 Department of Decision–Making Theory 9

- 1.1 Relaxation in Optimization Theory and Variational Calculus 12
- 1.2 Inconsistent Marginal Problem 13
- 1.3 Optimal Design of Topology and Material of Mechanical Structures 14
- 1.4 Tertiary Control of Voltage and Reactive Power 16
- 1.5 Imperfectly Specified Events in Failure Diagnosis of Discrete Event Systems 17
- 1.6 The Database of Ghetto Terezin 18
- 1.7 Mathematical Programs with Equilibrium Constraints . . 18
- 1.8 Two-block-factor Sequences and One-dependence . . . 19
- 1.9 Conditional Independence and Graphical Models 21

2 Department of Control Theory 23

- 2.1 Robust Regional Pole Placement 29
- 2.2 Robust Stabilization 30
- 2.3 Numerical Methods for Polynomial Matrices - The Next Generation 30
- 2.4 Polynomial Toolbox 31
- 2.5 Model Matching for Periodic Systems 32
- 2.6 Space-Time Control Systems 33

2.7 *Feedback Control of Affine Nonlinear Singular Control Systems* 33
2.8 *Constructive Nonsmooth Stabilization of Triangular Systems* 34
2.9 *Robust Nonlinear Control* 36

3 Department of Adaptive Systems **37**
3.1 *Computer-Aided Design of Adaptive Controllers* 45
3.2 *On-Line Fault Detection with Non-Linear Models* 47
3.3 *Fast Parallel Computations* 49
3.4 *Intelligent Systems for Prediction* 52
3.5 *Robust Decentralized Control of Large-Scale Systems* . 53
3.6 *Data Processing in Radiation Protection* 55
3.7 *Estimation Tasks in Nuclear Medicine* 56

4 Department of Stochastic Informatics **57**
4.1 *Estimating Information* 63
4.2 *Recursive Estimation of Linearly or Harmonically Modulated Frequencies of Multiple Cisoids in Noise* 64
4.3 *New Statistics for Testing Hypotheses* 66
4.4 *MCMC Estimates for Regression Models* 67

5 Department of Econometrics **69**
5.1 *Fuzzy Coalition Games* 75
5.2 *Generator of Fuzzy Quantities* 76
5.3 *Dynamic Economic Systems Under Uncertainty: Multi-stage stochastic and dynamic programming approaches* 77
5.4 *Stochastic Control Application to International Markets* . 80
5.5 *A Bivariate Integral Control Mechanism Model of Household Consumption* 81

5.6 Information and Capital Markets 81
5.7 A Market Structure Efficiency 83

6 Department of Pattern Recognition 85
6.1 Statistical Pattern Recognition 89
6.2 Probabilistic Neural Networks 91
6.3 Range Image Segmentation 92
6.4 Image Data Reconstruction 93

7 Department of Image Processing 95
7.1 Multichannel Blind Deconvolution 98
7.2 Significant Point Detection in Multiframe Images 99
7.3 An Invariant Approach to Degraded Image Analysis . . 101
7.4 3-D Supercomputer Modeling and Visualization of Rigid Particles Motion in Viscous Fluid 102

References 105

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Grants and Projects:

- J. Outrata: Non–smooth analysis in problems of continuum mechanics.
  (Grant GA AV ČR No. A107 5707)

- J. Pik: Discrete event theory application in development of dependable software.
  (Grant GA ČR No. 102/96/1671)

- J. Pik: Complexity reduction methods for discrete event control models and algorithms.
  (Grant GA AV ČR No. 207 5505)

- Z. Schindler: Local and global information network of antibiotic resistance.
  (Grant GA ČR No. 310/96/0588)

- Z. Schindler: The database of Ghetto Terezín.
  (Project supported by Terezín Initiative, Terezín Initiative Foundation and Terezín Memorial).

University Courses:

- Faculty of Mathematics and Physics of the Charles University
  - Selected topics of optimization theory.
    (T. Roubíček)
  - Nonlinear partial differential equations and inequalities. (T. Roubíček)
  - Modern optimization theory. (J. Jarušek, J.Outrata)

- Faculty of Applied Sciences of the University of Western Bohemia
  - Systems of perception and understanding. (J. Pik)

- Faculty of Informatics and Statistics of the University of Economics
  - Knowledge representation and processing.
    (R. Jiroušek)
  - Bayesian networks. (R. Jiroušek)
  - Intelligent systems. (R. Jiroušek)
  - Logics. (J. Vejnarová)

- Faculty of Physical and Nuclear Engineering of the Czech Technical University
  - Probabilistic methods in artificial intelligence.
    (R. Jiroušek)

Our Visitors:

- Prof. Glen Shafer (Rutgers University)
- Prof. C.Carstensen (University of Kiel)
- Dr. J. Vercholantsev (YAD VASHEM, Jeruzalem).

Most of the research activities of the department belongs to the field of applied mathematics. We are interested in theoretical problems as well as problems connected with implementation of methods in the following areas:

- artificial intelligence,
- uncertainty processing in expert systems,
- discrete event systems,
- mathematical optimization,
- differential equations.

1.1 Relaxation in Optimization Theory and Variational Calculus

Optimization and variational problems (including noncooperative game problems) often fail to have a solution (typically due to various oscillation or/and concentration effects). Then a need of their extension (=relaxation) is urgent. A fairly general approach based on a so-called convex-compactification theory has been developed during past few years, and now comprehensively published in the monograph [177]. It enables both to get existence (and also stability, approximation, etc.) results and to pose selective optimality conditions, covering thus by a unifying manner relaxation schemes known so far. To this goal, Young measures and their various generalizations are typically used as so-called relaxed controls or mixed strategies.

Recently, this sort of research continued in various directions, resulting e.g. to the publications [106, 107, 176]. In particular, it enables effective modelling of complicated microstructure often appearing in various physical systems involving e.g. nonlinear elasticity, magnetism, etc.

1.2 Inconsistent Marginal Problem

In *expert systems* with probabilistic background, there exists a standard requirement to reconstruct a *joint distribution* from different *pieces of knowledge*. This joint distribution is then used as a tool to generate *aposteriori probabilities* of predicted variables given some fixed values other variables take. This search for a joint distribution is referred to as *marginal problem* (Kellerer). The predominant direction in contemporary advanced expert systems with probabilistic background represents the mathematical model of *Bayesian network* (Lauritzen, Spiegelhalter, Shachter). This approach makes possible to cope with the "dimensionality curse" by assuming conditional independence for variables not mentioned explicitely in the model. Another approach (dropping the independence assumption) to the solution of the *marginal problem* is possible but only for distributions on small *finite sets*. In general, there is a difference in algorithmical treatement of the problem for *objective* and *subjective* (de Finetti) *Bayesian approach*. The essence of the latter can be seen e.g. in works of Scozzafava, Gilio, Colleti and Vicig.

As far as the former approach is concerned: Sometimes, the IPFP algorithm (Stefan, Deming) is used to solve the *marginal* *problem*. Cheeseman suggests to use Lagrange multipliers to respect constraints imposed by *marginals*. In the previous paper by Kříž, there is an algorithm presented (*Tetris*) checking if a set of *marginals* is consistent (and in positive case supplying one of feasible solutions). In [121], a modification of this algorithm (*Pentis*) is given that looks for the "best" approximation in l_1 norm even if the *marginals* are not consistent. The algorithm *Pentis* uses as input confidence weights for individual less-dimensional distributions that may reflect their statistical relevance or some other aprioristic estimation of their value as a source of information. The *Pentis* algorithm can operate efficiently on problems including not more than 10 dichotomical variables.

1.3 Optimal Design of Topology and Material of Mechanical Structures

One of the basic problems of structural engineering reads: *For a given set of boundary conditions and a given set of loads, find the stiffest structure of a given volume that is able to carry the loads.* First we concentrated on structures consisting of bars that are connected at joints (so-called trusses). The design variables are the *bar volumes* and the goal is to choose the volumes (where the total volume is limited) such that the truss becomes as stiff as possible. In mathematical terms, we maximize (with respect to bar volumes) the minimal (with respect to displacements) potential energy of the structure. Recently, we have shown how to reformulate the problem as a convex mathematical program that can be efficiently solved by the interior-point methods [66].

The problem is further generalized by adding so-called *displacement constraints*. Here we require that the displacements at selected nodes do not exceed given values (this reminds the unilateral contact problem, but is in fact much more complicated). We proposed a new bilevel programming approach to this problem. The primal goal (upper-level) is to satisfy the displacement constraint as well as possible—we minimize the gap between the actual and prescribed displacement. The second goal (lower-level) is to minimize the compliance—we still want to find the stiffest structure satisfying the displacement constraints. On the lower level we solve a standard truss topology problem using the interior-point algorithm. The overall bilevel problem is solved by means of the so-called implicit programming approach. This approach leads to a nonsmooth optimization problem which is finally solved by a nonsmooth solver [98].

Secondly, we concentrated on optimum design of a material in a two- or three-dimensional continuum elastic body. The design variables are the *material properties* which, in this approach, may vary from point to point. The objective is the same as in the truss problem: we maximize (with respect to material properties) the minimum potential energy, which characterizes the state of equilibrium for a given material under a given load. The problem looks quite complicated at a first glance: in two (three) dimensions, the design variables are the six (twenty one) elements of the symmetric elasticity tensor. But we can analytically reduce it to a problem with only *one* design variable—the trace of the elasticity tensor. The elements of the optimal matrix are then fully recoverable from the optimal trace. The reduced problem is discretized by the finite element method and leads again to a convex mathematical program solved by an interior-point method [239].

Finally, we concentrated on the the problem of material design under *multiple load* conditions. Given a set of independent loads, we want to find an elastic material which resists equally well to all these loads. Having in mind the so-called worst-case formulation of the problem, we reformulated it as a *semidefinite mathematical program* (SDP). Such a program can be numerically solved by means of recently developed SDP algorithms, based again on interior-point ideas [239].

1.4 Tertiary Control of Voltage and Reactive Power

Energetical system at transmission levels 220 and 400 kV can be described as a large sparse unoriented graph where nodes correspond to substations and branches to lines.In each node, there are four mutually dependent phenomenological local variables namely voltage module U, voltage phase ϕ, real power P and reactive power Q. (The frequency of the system is a global variable and therefore handled separately.) Real power generated and consumed in the system can be seen as externally given time function. The task of the controller is to keep the voltage profile over the network within the limits and keep the transfer losses as low as possible. The action variables are reactive power in each source node produced by primary Q controllers at individual generator units. The reactive power consumption is determined not only by the final users via distribution transformers but even the lines themselves may generate reactive power according to the transmitted real power. The problem of U/Q control may be stated as an optimization (minimization of thermal losses on line resistances R) subject to above mentioned constraints. The problem is *nonlinear* (quadratic and trigonometrical functions), *hierarchical* in space (units, plants or substations, central dispatching) and in time (seconds, 1 minute, 15 minutes) and *distributed* (only some data can be transferred to the centre due to limited lines capacities). Each 15 minutes, tertiary control calculates set point values for secondary voltage controllers in ten so called pilot substations. The quasi-optimal solution is looked for with the help of simulated annealing in the multidimensional complex linear space of several hundred state variables. In [122], some problems are formulated (and their solutions suggested) arising from the difference between the above mentioned model and the real electrical system. The algorithmical solution has been implemented and is put to tests in the Central Dispatching of Czech Power Company ČEZ,a.s..

1.5 Imperfectly Specified Events in Failure Diagnosis of Discrete Event Systems

Imperfectly specified events in the language-based approach to failure diagnosis of discrete event systems are considered. As this approach is set in the framework of formal languages and corresponding state machine representations, the diagnoser is a finite state machine constructed from the model of the system. The diagnosis provided by the diagnoser depends on two factors: (i) the system model from which the diagnoser is synthesized, and (ii) the observation sequences considered by the diagnoser. Several sources of observation errors are considered: the diagnoser may miss seeing an event, it may assume that an event occurred when none did, or it may mistake one event for another.

An event inconsistent with the current state of the diagnoser may be contained in the observation record in the process of diagnosis. The differences between the event sequence generated by the system and the event sequences of the diagnoser are modelled using the event-to-event operations and the corresponding rho-bar distances based on the transformations of event sequences are determined. Supposing an inconsistency in observations, the diagnoser enters the state following the event belonging to the more likely or optimal event sequence representation. An extension of the diagnostic procedure based on a general form of the transformation of event sequences is proposed in [167, 166].

1.6 The Database of Ghetto Terezin

The relational database of prisoners of the Second World War concentration camp Terezin was further developed.

Currently, historical research of personal data of prisoners from the German territory is being performed. As available archival documents are of different validity, the database must be continuously modified to reflect the diversity of incoming data. The data must be kept in uniform consistent form for all documentation materials. The majority of processed personal records have been already authenticated; unclear records are further worked on. The database is designed so as to provide the most credible information about any Terezin prisoner even if the search criteria are not reliable.

The database is intended to be the basic source of data for the publication of the third volume of The Terezin Memorial Book. The database concept fulfils the general demands posed on databases of the victims of the Holocaust and can be utilized for verification of similar type of data in other foreign institutions.

1.7 Mathematical Programs with Equilibrium Constraints

These programs are especially difficult, if the underlying equilibrium problems possess multiple solutions for some values of the control variable. We restricted our attention to equilibria governed by nonlinear complementarity problems which one can encounter in various mechanical or economic models. For deriving 1st-order necessary optimality conditions we used the tools of nondifferentiable calculus of B. Mordukhovich in the framework of so-called implicit programming approach. This technique, under a variant of nonsmooth Mangasarian-Fromowitz constraint qualification, led to useful, sharp optimality conditions [159]. When applied to programs, where the underlying equilibrium problems possess unique solutions for all values of the control variable, our conditions are superior to those, derived by the nondifferentiable calculus of F. Clarke. It seems that they could be used also to construct an efficient numerical method.

1.8 Two-block-factor Sequences and One-dependence

Let $\eta = (\eta_i;\, i \geq 1)$ be an i.i.d. sequence with the variables ranging in a measurable space $(U, \mathcal{U})$ and let f be a measurable function defined on the product space $(U^{m+1}, \mathcal{U}^{m+1})$, $m \geq 0$, with its values in a measurable space $(S, \mathcal{S})$. The random sequence $(f(\eta_i, \eta_{i+1}, \ldots, \eta_{i+m});\, i \geq 1)$ is called $(m+1)$-*block-factor* of the sequence η. The problem of determining which random sequence $\xi = (\xi_i;\, i \geq 1)$ is equal in distribution to an $(m+1)$-block-factor has been likely contemplated in past by many probabilists.

A sequence ξ having the distribution of an $(m+1)$-block-factor must be, trivially, strictly stationary and m-*dependent* in the sense that $(\xi_i;\, j > i \geq 1)$ is stochastically independent of $(\xi_i; i \geq j+m)$ for every $j > 1$. The fact that these two necessary conditions are not sufficient, or in other words, that the distributions of $(m+1)$-block-factors do not exhaust the distributions of all m-dependent stationaly sequences, $m > 0$, was already mentioned by Ibragimov and Linnik decades ago. The first published examples of one-dependent stationary sequences which are not two-block-factors appeared much later, see *Ann. Probab.* (***17***, 1989, 128–143). Markov sequences were examined from this point of view by Aaronson, Gilat and Keane in *J. Theoretical Probab.* (***5***, 1992, 545–561) where an example of a five-state one-dependent homogeneous Markov sequence which is not a two-block-factor is presented. Moreover, it was proved that there is no such example with less than five states. More sophisticated examples of one-dependent stationary sequences which are even not m-block-factors for any $m \geq 0$ were introduced recently in *Ann. Probab.* ***21***, 1993, 2157–2168.

We succeded to relate the problem which sequences have the distributions of $(m+1)$-block-factors to known results on representations of partially exchangeable random arrays. This provided a characterization of $(m+1)$-block-factors in terms of jointly exchangeable and dissociated arrays. If S is a Polish space then as a consequence of the characterization we proved that the distributions of two-block-factors form a close set under week topology. This fact implies that they are not dense in the set of one-dependent stationary distributions provided S has at least two elements.

Further we employed the standpoint of arrays to simplify and strengthen the results of Aaronson, Gilat and Keane on the five-state Markov sequence. By transparent graphical manipulations we demonstrated an inequality concerning the superdiagonals of arrays. This inequality enables to modify slightly their example to obtain a five-state one-dependent Markov sequence which is not a two-block-factor and has positive probabilities of all cylinders.

Comparison of several graphical approaches to description of probabilistic conditional independence structures was made in [194]. The following questions were studied within different classes of graphs and an overview of related results was given:

- correctness, that is the question whether every graph within the considered class of graphs describes some probabilistic conditional independence structure,
- characterization of the ascribed conditional independence models in terms of formal properties of independency models,
- graphical characterization of equivalent graphs, that is graphs (within the considered class of graphs) describing the same conditional independence structure,
- existence of a distinguished representative within each class of equivalent graphs.

As concerns the considered classes of graphs, except traditional frameworks of undirected graphs (Markov networks), directed acyclic graphs (Bayesian networks) and chain graphs several further classes of graphs were involved. That is the class of (general) directed graphs, the class of reciprocal graphs and the class of annotated graphs.

An algorithm which changes every chain graph into the corresponding largest chain graph is proposed in the paper [196]. It gives as a by-product a certain graphical characterization of largest chain graphs. The paper [240] deals with the problem of choice of relevant symptoms in medical decision making.

Further research activity is devoted to refinement of the theory of *annotated graphs*. These graphs were introduced by A. Paz and R. Y. Geva with the aim to describe very wide class of independency models in graphical way. Roughly (but a bit imprecisely) said, annotated graphs are graphs whose edges are annotated by sets of remaining nodes. If such a graph satisfies certain regularity conditions, then a 'membership testing algorithm' ascribes a graphoid to it. However, the main aim of introducing of annotated graphs is to have a condensed graphical record for description of graphoid closures of unions of graphical models. It was shown that for every sequence of embedded undirected graphs $G_1, \ldots, G_n$ there exists a regular annotated graph describing exacly the graphoid closure of the union of conditional independence models ascribed to $G_1, \ldots, G_n$. In particular, from the point of view of description of independency models, annotated graphs generalize both undirected graphs, directed acyclic graphs and chain graphs.

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General

The research in linear control theory has a long tradition at the Institute. In early 1960s, under the leadership of Professor Strejc, researchers at the Institute made significant developments in both transfer-function and state-space methods. During the 1970s and the 1980s members of the Department, lead by Professor Kučera, obtained significant results which launched an entirely new area of research worldwide. Among these is a parametrization of all controllers that stabilize a given plant (known as the Youla-Kučera parametrization) and the design of control systems via polynomial equations. In the 1990s, the research activities of the department range from robust control to nonlinear systems.

Application research in the Department concentrates on numerical methods for control system simulation and design. This results in various original software packages for control and simulation.

Activity of the Department in international technical and scientific societies is remarkable. Our members serve in governing bodies of the International Federation of Automatic Control (IFAC), of the Institute of Electrical and Electronic Engineers (IEEE) and of the International Federation of Information Processing (IFIP).

V. Kučera is the Editor-in-Chief of the scientific journal Kybernetika, published bi-monthly by the Institute. This is a flagship journal of the Czech control and information community and it has a worldwide readership. The journal is monitored by Science Citation Index and its impact factor is 0.156.

Grants and Projects

S. Čelikovský, Nonlinear Systems: New Approaches to Control and Detection, (Grant Agency of the Academy of Sciences of the Czech Republic);
J. Doležal, Prague Technology Center (Honeywell);
V. Kučera, Robust Control Systems Design (Grant Agency of the Czech Republic);
V. Kučera, Théorie des systèmes linéaires et non linéaires (CNRS France);

V. Kučera, Dynamic Control & Management Systems in Manufacturing Processes (European Community – Copernicus);
V. Kučera, Advanced Methodologies and Tools for Manufacturing Systems (European Community – Copernicus);
V. Kučera, Control Engineering and Research (Swiss National Science Foundation);
V. Kučera, Structure of Linear Systems (Tübitak-Doprog, Turkey);
M. Šebek, Algorithms for CAE Based on Modern Polynomial Methods in Control (European Community – Copernicus);
M. Šebek, Systems with Uncertainty and Constraints, (Czech-French project – Barrande).

Teaching Activities

V. Kučera, Faculty of Electrical Engineering, Czech University of Technology, Prague: Algebraic Approach to Control System Design (postgraduate), Linear Systems (graduate).
M. Šebek, Faculty of Electrical Engineering Czech University of Technology, Prague: Modern Control Theory
P. Zagalak, CINVESTAV del IPN, Mexico: Linear Systems (postgraduate).
V. Kučera is a member of the Acreditation Board of the Czech Republic Government and a member of the Scientific Boards of two universities (Czech University of Technology, University of Western Bohemia) and two faculties (Faculty of Electrical Engineering, Prague and Faculty of Mechatronics, Liberec).

Invited Lectures

V. Kučera, The Riccati equation of optimal control, Innsbruck, A
V. Kučera, A bridge between state–space and transfer–function

methods, Istanbul, TR
V. Kučera, Robust regional pole placement, High Tatras, SK
V. Kučera, Control theory and forty years of IFAC, Fukuoka, J
V. Kučera, Feedback realization of cascade compensators, Miedzyzdroje, Pl
V. Kučera, Robust and optimal control via parametrization, Smolenice, SK

Our Visitors

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A. Fradkov, University of St. Petersburg, RU
G. Garcia, LAAS CNRS, Toulouse, F
D. Henrion, LAAS CNRS, Toulouse, F
F. J. Kraus, ETH Zürich, CH
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Representation in International Societies

J. Doležal – President of the Czech Committee for IFIP and

Full Member Representative in IFIP General Assembly;

V. Kučera – Vice President of IFAC, Chairman of IFAC Technical Board and a member of IFAC Technical Committee on Linear Systems;
– President of the Czech Committee on Automatic Control;
– Fellow of IEEE and a member of the IEEE Control Systems Society Board of Governors;

M. Šebek – A member of the IFAC Policy Committee and of the Technical Committee on Control Design;
– Member of the Conference Editorial Board of the IEEE CSS;
– Executive Committee member of the Czechoslovakia IEEE Section;
– President of the Czech IEEE Control Systems Society Chapter.

Research

The current research objectives in the Department of Control Theory are in the analysis and design of control systems. Three main research directions are as follows:

- analysis and design of linear systems including robust control;
- numerical methods for control systems analysis and design;
- analysis and design of nonlinear control systems.

Interest is focused on both theoretical studies and computer implementation of the results obtained.

2.1 Robust Regional Pole Placement

A typical control design scenario begins with a system to be controlled and a mathematical model which includes uncertain quantities. For example, the mathematical model might involve various physical parameters whose values are specified only within given bounds. Other uncertainties could arise from disturbances affecting the system or from a shift of its regime. Finally, modelling errors should be considered that result from using simplified mathematical models of real systems achieved by ignoring certain dynamical parts or by linearization. Modern control theory addresses problems involving uncertainty in several ways. However, a fixed and off–line designed controller – a robust controller – that guarantees a desired performance is preferred by industry for reliability and safety reasons.

A very simple design method for linear systems is described in [116], [117] that achieves a *robust pole placement* within a specified region of the complex plane, in the face of parametric uncertainties in the coefficients of the system transfer function. It is assumed that the unknown parameters live in a *convex* polytope in of the parameter space. The controller design is then reduced to the solution of a system of linear inequalities. If these inequalities are consistent, one obtains any and all robust controllers parametrized in a simple way. Additional design specifications can be met by an appropriate selection of the parameter. Paper [103] provides one possible generalization of this design method for multi–input multi–output systems.

This research was supported by the Grant Agency of the Czech Republic under contract 102/97/0861.

2.2 Robust Stabilization

While robust stability analysis of systems with parametric uncertainties has been extensively studied, the synthesis results are missing as yet even for the simplest case of a single uncertain parameter. One of the first design procedures has been developed by an original combination of algebraic and geometrical approaches. For the plant modeled by the transfer function

$$\frac{b(s) + r\beta(s)}{a(s) + r\alpha(s)},$$

where r is an uncertain real parameter while $a(s), b(s), \alpha(s)$ and $\beta(s)$ are given polynomials (in Laplace transform operator s), a robust controller is designed such that the resulting feedback system remains stable for any value of r from a given interval $[r_{\min}, r_{\max}]$. The method is based on quadratic forms over Hermite-Fujiwara matrices and leads to the solution of a concave minimization problem. It parameterizes all robustly stabilizing controllers up to a given order and reveals both necessary and sufficient conditions for solvability.

The results were achieved in cooperation with LAAS CNRS, Toulouse, France under the Barrande project no. 97026.

2.3 Numerical Methods for Polynomial Matrices - The Next Generation

Polynomial methods have been the major contribution of the institute to linear control. The methods are characterized by extensive use of polynomial matrix operations and equations. Their successful industrial application naturally relies on good numerical algorithms for polynomial matrices.

A new generation of computational procedures has been developed. They are based on interpolation and Sylvester matrix approach and appear to be more efficient as well as more reliable than classical routines.

The new algorithms include solvers for various special polynomial matrix equations and first numerically stable procedures for triangularization, greatest divisors and rank evaluation of polynomial matrices, etc.

2.4 Polynomial Toolbox

A software package for MATLAB called Polynomial Toolbox was developed to make the achievements in polynomial control theory easily available for practical applications. The Toolbox was designed to perform various computations with and on polynomial matrices, to solve many types of polynomial matrix equations and to handle various problems of linear control and signal processing.

The Polynomial Toolbox is aimed at industrial as well as classroom use in the fields of control systems, signal processing and applied mathematics. It consists of almost one hundred macros that are often based on original algorithms. The Toolbox has been developed in cooperation with the Department of Applied Mathematics at the University of Twente, NL within a European joint project COPERNICUS project CP 93:2424: Algorithms for CAE based on modern methods in control.

Polynomial Toolbox is available as freeware through the Toolbox WWW home page at URL

`http://www.math.utwente.nl/polbox/`

Future users are welcome to register and download the Toolbox along with its hypertext manual and tutorial. They can obtain various information on the Toolbox, its application in various engineering fields and university courses, numerical algorithms used and future plans.

2.5 Model Matching for Periodic Systems

The linear systems whose coefficients are periodic functions of time constitute a very important class of time–varying systems. For one thing, they describe many useful systems of physical and engineering importance. For the other thing, they are amenable to analysis. In particular, control problems for *discrete–time periodic systems* can be recast as equivalent problems in the realm of time–invariant systems by exploiting the isomorphism that exists between the two classes of systems. Most often used are the *lifted* and the *cyclic* time–invariant representations of periodic systems.

Using the cyclic representation, the *model matching* problem was solved in [18], [20] for discrete–time periodic systems. Given such a system, the problem is to find a periodic state–feedback control law such that the closed–loop system has a prespecified input–output map. This map can be expressed by means of the transfer function of the cyclic representation of the given periodic system to be matched. Matching conditions are given in terms of transmission zeros. In particular, it was shown that a periodic system can always be matched with a time–invariant model. Internal stability of the resulting system is studied in [19].

This work was supported by the Centro di Teoria dei Sistemi of the Italian National Research Council.

2.6 Space-Time Control Systems

Many industrial processes are described by variables, which are not only evolving in time, but are also distributed in space. Typical examples include pipelines, paper machine, cement furnace and steel rolling mills. Some control problems for such systems are difficult to solve by individual PID controllers and they need a deeper analysis and synthesis via transfer functions. As the space-time systems are described by partial differential equations, the transfer functions are not rational in complex variable p but more complicated functions (algebraical, exponential). To be usable for synthesis, they must be approximated by rational ones.

In recent years, attempts are seen in the literature, to use 2-D rational functions (polynomial fractions in two complex variables: space s, time p). Originally, the theory of 2-D systems began for image processing but then was adopted for space-time control systems. The device of 2-D Laplace and Z transform was elaborated, properties of signals and systems (stability, controllability, poles, zeros) analyzed. Some properties are similar to those of the standard 1-D systems, others are surprisingly different. The aim of the research is to use 2-D polynomial equations for control synthesis.

2.7 Feedback Control of Affine Nonlinear Singular Control Systems

The feedback control problems for affine nonlinear singular systems are discussed in [123]. These systems are important in many applications, like constrained mechanical systems, and received a lot of attention recently. Basically, they may be considered as the following system of differential and algebraic equations

$$\dot{x} = f_1(x) + p_1(x)z + g_1(x)u$$

$$0 = f_2(x) + p_2(x)z + g_2(x)u,$$

where x is n-dimensional vector of the so-called differential variables, while z is s-dimensional vector of the so-called algebraic variables and u is m-dimensional input. All vector fields and functions are of appropriate dimensions and of C^∞ quality.

Since the above systems may not have unique solutions for given initial conditions, the so-called regularization problem is considered, i.e. whether it is possible to achieve existence and uniqueness of solutions via suitable feedback. This problem is solved using appropriate modification of the well-known constrained dynamic algorithm. The obtained solution provides an efficient constructive algorithm how to check feedback regularizability and then compute the corresponding feedback.

Later, for a given regularized system, other feedback control problems are solved in a similar, constructive, fashion. These are noninteracting control via suitable feedback and feedback exact linearization problems.

2.8 Constructive Nonsmooth Stabilization of Triangular Systems

The problem of local asymptotic continuous feedback stabilization of single-input nonlinear systems is considered in [2]. The explicit construction of a continuous asymptotically stabilizing feedback for a class of nonlinear systems is provided. Computer simulations are included to show practical applicability of the presented approach.

Namely, the so-called triangular form systems (TF) or simply triangular systems are considered, i.e. the following single-input systems

$$\begin{aligned}
\dot{x}_1 &= f_1(x_1, x_2) \\
\dot{x}_2 &= f_2(x_1, x_2, x_3) \\
&\vdots \\
\dot{x}_{n-1} &= f_{n-1}(x_1, x_2, \ldots, x_n) \\
\dot{x}_n &= f_n(x_1, x_2, \ldots, x_n) + u g_n(x).
\end{aligned}$$

The properties of TF systems heavily depends on quality of interconnections between each two neighboring rows, or cascades (alternative terminology are the cascade systems). This is expressed at i-th row by partial derivatives $\frac{\partial f_i}{\partial x_{i+1}}(0)$, if it is nonzero for and for all $i = 1, \ldots, n-1$, then the system is exact state and feedback equivalent to the linear system. Otherwise (the so-called singular TF), the situation becomes more complicated, since even approximate linearization fails to be controllable, i.e. the TF system in question may not be stabilizable. Nevertheless, the singular TF are being intensively studied and have some applications, e.g. in some models of weakly coupled mechanical systems. Difficulty here consists in the fact that higher order nonlinearities are becoming crucial for the system behaviour. The sufficient conditions for stabilization of the singular TF systems were revealed by Coron and Praly in 1991. These conditions are easy to check and require specific quality of interconnections between cascades. Nevertheless, they do not provide explicit and effective way, how to compute the stabilizing feedback.

This drawback has been removed by [2], where a clear algorithm to compute stabilizing feedback is provided. Computer simulations are included to show viability of that approach. Construction of the stabilizing feedback is quite straightforward, but mathematical prof of stability is quite complicated and completed fully only for a certain subclass of singular TF. Nevertheless, computer simulations experimentally confirm its applicability to all singular TF systems.

2.9 Robust Nonlinear Control

Our research on nonlinear H_∞ control was focused on extending results of [8] to certain classes of nonstandard nonlinear plants and several new results have been obtained in this area.

We considered nonlinear affine plants whose measurement output is of dimension larger than the dimension of the external input. This problem was, under proper assumptions, transformed to the problem of stabilization by means of output injection, and solving a Hamilton-Jacobi partial differential inequality arising in the H_∞ state-feedback control. General sufficient solvability conditions were derived; explicit solutions were obtained in the local and semilocal cases. The former case concerns a certain neighborhood of the origin in the closed loop state-space; in that case, we are able to obtain some necessary conditions for solvability of the given problem. The latter one assumes that the closed loop state trajectories are restricted to a neighborhood of an invariant manifold. This assumption means that we know the initial state of the plant up to a high degree of accuracy and the effect of unmodelled disturbances can be neglected. On the other hand, the states of the plant need not be restricted to a small region around the origin. The above mentioned nonlinear output-injection stabilization problem is then transformed to a stabilization problem for a linear, parameter-varying system. The issue of the controller order was addressed and a reduced order controller was obtained in the local case [7].

3 Department of Adaptive Systems

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Petr Klán	–	information in prediction
Rudolf Kulhavý	–	recursive nonlinear estimation
Petr Nedoma	–	software engineering
Petr Pecha	–	radiation protection
Jan Schier	–	parallel signal processing

Postgraduate Students:

Luděk Berec	–	structure estimation
Jiří Rojíček	–	robust control design
Ludvík Tesař	–	nonlinear recursive estimation
Markéta Valečková	–	Markov chains
Tatiana Guy (CEGS)	–	spline based controllers
Nataša Khailová (CEGS)	–	fault detection
Hong Gao (CEGS)	–	Markov neural nets
Ladislav Jirsa	–	statistics in biophysics
Petya Ivanova (CEGS)	–	intelligent systems for prediction

Activities of the Institute fall into cybernetics and informatics, into the fields dealing with analysis and design of systems generating predictions, making decisions or controlling other systems. Our department deals with systems that have the added ability to modify their behaviour in correspondence with the changing environment or operating conditions. This essential feature enhances the efficiency of the systems performing the tasks listed above.

We have been active in this area for decades and have reached significant conceptual, theoretical, algorithmic, software and application results. Gradually, the Bayes-based theory of decision making under uncertainty has become fixed — and successful — methodological kernel of our work.

The interplay between theory and (always limited) computing power is the leitmotiv of our current research. This difficult problem is addressed from all possible directions:

- We learn what complexity means in reality by solving practical demanding problems in radiation protection, in economic and technological systems, in signal processing, in nuclear medicine etc.
- We improve gradually our know-how in order to widen applicability of “classic” adaptive systems to more and more complex situations.
- We inspect theoretically possible novel approaches to construction of adaptive systems.

This text describes our effort to widen applicability of theoretically justified adaptive systems. However, no report can fully reflect real contents of papers, seminars and discussions with partners in academe as well as applied sectors. Please, take this incomplete information as an invitation to meet us and to enjoy creative and friendly atmosphere which we consider just as important as the formal results.

Grants and Projects

The results described in the next sections have been obtained due to the effort of the research team. Nevertheless, the achievements would be impossible without substantial support from many sources. The following list is meant as an acknowledgment.

- L. Bakule – *Robust decentralized control of large-scale systems* (GA AV ČR A2075802)
- J. Böhm – *Adaptive and predictive control with physical constraints* (Copernicus CP94-1174, [PREDCON])
- J. Böhm (V. Bobál, VUT, Brno) – *Practical aspects of self tuning controllers: algorithms and implementation.* (GA ČR 102/96/0927)
- H. Gao – *Bayesian approximate recursive identification and on-line adaptive control of Markov chains with high order and large state space* (GA ČR 102/98/P059)
- J. Kadlec (J. Bayer, FEL ČVUT, Praha) – *Novel control structures for production systems* (GA ČR 102/95/0926)
- M. Kárný – *Decision-support tool for complex industrial processes based on probabilistic data clustering* (Esprit 25729)
- M. Kárný – *Adaptive dynamic elements and their connections for dynamic decision making under uncertainty* (GA AV ČR A2075606)
- M. Kárný (J. Mošna, ZČU, Plzeň) – *New approach to optimality and adaptivity of uncertain systems* (GA AV ČR A2147701)
- R. Kulhavý – *Global approximation of model in recursive Bayesian parameter estimation* (GA AV ČR A2075603)
- R. Kulhavý (O. Vašíček, MU, Brno) – *Modelling of transitive economy using short time series* (GA ČR 402/96/0902, success-

fully finished)

- R. Kulhavý – *Qualitative and analytical model based fault detection for chemical processes* (Copernicus COP-94 01320, [FDI])
- P. Nedoma – *Enhancement of the EU decision support system RODOS and its customisation for use in Eastern Europe* (Copernicus PL963365, [RODOS])
- P. Nedoma – *Adaptive systems: theory, algorithms and software for praxis* (GA ČR 102/97/0118)
- J. Schier – *Fast parallel algorithms for adaptive identification and LQG control design* (GA ČR 102/95/1614, successfully finished)
- J. Schier – *PTT and OTT enhancement for the collision avoidance radar* (Dutch STW agency DEL 22.2733, [Poet])
- J. Schier – *A high speed logarithmic arithmetic unit* (Esprit 23544) (agreed association with a running project)

University Courses

Education is an integral part of the research. It is reflected in relatively high number of MSc theses and undergraduate research projects supervised by us. To attract the interest of students, the members of the Department give regular undergraduate courses:

- Faculty of Physical and Nuclear Engineering, ČVUT
  Adaptive Control
- Faculty of Electrical Engineering, ČVUT
  Estimation and Filtering Theory
  Selected Applications of Estimation Theory
- Faculty of Transportation, ČVUT
  Principles and Applications of Parallel Computation
- 2^{nd} Medical Faculty, Charles University
  Basic Theory of Data Processing
- Faculty of Chemical Technology, University of Pardubice

Automatic Control Theory

International dimension in teaching has been reached through the departmental activities in

- *Central European Graduate School in Systems and Control Theory* (CEGS) established by ÚTIA together with the Czech Technical University, Computer and Automation Institute of Hungarian Academy of Sciences and the University of West Bohemia.

Conferences

We hosted two of them

- International FDI Workshops at Mariánská, Krušné hory

both related to our FDI project. We are also preparing

- 3rd IEEE Workshop CMP'98 *Computer Intensive Methods in Control and Data Processing: Can we beat curse of dimensionality?*.

Both IPC members and the experts who accepted to give invited talks are more than impressive (consult our web page).

Guests

- *T. Guy*, (Ukraine),
H. Gao, D. Bo, (both People's Republic of China),
P. Ivanova (Bulgaria) and *N. Khailová* (Russia),
are studying various aspects of adaptive systems within the framework of *Central European Graduate School in Systems and Control Theory* (CEGS) we are organizing.
- *Katya Braun-Vaille* (Guatemala) joined shortly CEGS, too.
- *Dr. R. Jasiulionis* (Lithuania) visited us in connection with the RODOS project.
- *Dr. Michel Kinnert* (Belgium), *Dr. D. Jurišičic* (Slovenia), *Prof. K. M. Hangos, Dr. G. Szederkényi* (both Hungary) visited us in

connection with FDI project.

- *Kai Briechle* (Germany), student of Munich University, worked with us through the International Association for the Exchange of Students for Technical Experience.
- *B. Sviezeny*, I.S.E.P., Dept. of Telecommunication, Signals and Images, Paris organized summer practice of his students (4 BSc students from his school worked in the department for 3 weeks in July 1997).
- *Dr. P. Fuchs*, Department of Telecommunication, STU, Bratislava discussed with us cooperation in student visits and diploma works in ÚTIA.

Travels and International Cooperation

Conference trips were mostly connected with successful presentations. Thanks to the support gained from various grants, PhD students were given opportunity to visit Oxford, Reading, Brussels, Budapest. Coordination and working visits were mostly related to major European Community cooperation projects. Let us characterize the individual activities:

- L. Bakule
  cooperation with UPC, Barcelona, Spain,
  cooperation with UPV, Bilbao, Spain;
- L. Berec
  research within PREDCON Project, Oxford, UK,
  lecture ECC'97, Brussels, Belgium;
- J. Böhm
  coordination of PREDCON Project, Bratislava, SR,
  research within PREDCON Project, Oxford, UK;
  lecture, DYCOMANS Workshop, Varna, Bulgaria,
  lecture, DYCOMANS Workshop, Zakopane, Poland;
- H. Gao

lecture, IMACS Symposium Mathmod'97, Wien, Austria,
IFAC Symp. Safeprocess'97, Kingston U. Hull, UK;

- T. Guy
lecture, IASTED Conference on Modelling, Identification and Control, Anaheim, Austria;
- P. Ivanova
research visit, UMIST, Manchester,
review on PhD thesis, University of Sunderland, UK;
- L. Jirsa
study stay within PREDCON project, Oxford, UK;
- J. Kadlec
lecture and software presentation, Department of Telecommunications, STU, Bratislava, SR,
Esprit Information day, Brussels, Belgium,
Esprit Information day, Wien, Austria,
Femirc EU Information day, Stutgadt, FRG,
MathWorks Conference, Seoul, South Korea,
3. Zittauer Workshop Magnetlagertechnik, Zittau, FRG,
DSP Deutschland 97, Munchen. FRG,
ASIM Simulationstechnik, Dortmund, FRG,
coordination of FDI project, Budapest, Hungary,
study stay in Strathclyde University, Glasgow, UK,
coordination of PREDCON project, Oxford, UK,
U. of Newcastle, University-College Dublin, UK, Ireland,
study stay within PREDCON Project, Alpha Data, UK;
- M. Kárný
lectures ECC'97, Brussels, Belgium,
coordination of FDI project, Budapest, Hungary;
- P. Klán
lecture ECC'97, Brussels, Belgium;
- R. Kulhavý

lecture, IFAC Symp. Safeprocess'97, Kingston U. Hull, UK,
lecture, IFAC Symposium on System Identification, Fukuoka, Japan
invited lecture within a FDI course, ETH Zurich
invited lecture, ECC'97, Brussels, Belgium;

- P. Nedoma
  IAEA Conference, Special Topics Related to Level-3 PSA/DOSE calculation, Wien, Austria,
  study stay in Risoe National Laboratory, Roskilde and Technical University of Denmark, Lyngby,
  RODOS coordination meeting, Atomic Energy Research Institute, Budapest, Hungary,
  RODOS coordination meeting, Institute of Mathematical Machines, Kiev, Ukraine,
- P. Pecha
  lecture, IAEA Conference, Special Topics Related to Level-3 PSA/DOSE calculation, Wien, Austria,
  RODOS coordination meeting, Atomic Energy Research Institute, Budapest, Hungary,
  RODOS coordination meeting, Institute of Mathematical Machines, Kiev, Ukraine;
- J. Rojíček
  research within PREDCON project, Oxford, UK,
  research within PREDCON project, Bratislava, SR;
- J. Schier
  research within the *Colarado* project, Technical University Delft, The Netherlands;
- M. Valečková
  study stay, University of Valencia, Spain,
  study stay, Institute of Mathematics, Vilnius, Lithuania,
  research within PREDCON project, Oxford, UK

3.1 Computer-Aided Design of Adaptive Controllers

Adaptive controllers optimizing quadratic criterion with the help of recursively identified linear models having Gaussian process noise (LQG) proved repeatedly their full scale applicability (for our recent experiments on a heat-exchange station see [61]). Their efficient implementation is, however, non-trivial. The ambitious project of their computer-aided design launched several years ago made a significant progress. At present, a MATLAB toolbox ABET97 for the complete "batch" design is available [149]. ABET97 functions can be used to prepare MATLAB program that converts user's knowledge, objectives and restrictions into a completely pre-tuned controller. A project of interactive design of adaptive controllers, DESIGNER 2000, has been started as a natural continuation. The performed study [3] specified basic properties of DESIGNER 2000 and approved the feasibility of this project.

The present advanced state has been reached by combining theoretical, algorithmic and software activities. Let us characterize them.

Incorporation of prior knowledge. The user's prior knowledge about the system to be controlled together with data from preliminary experiments are converted into a prior model characterizing unknown parameters involved. A novel algorithm for the conversion has been proposed [81]. It weights the processed knowledge items so that a suitable compromise is found in spite of their imprecise, repetitive and contradictory nature. The obtained prior model:

- increases the chance to estimate a good model structure,

- serves for initiation of on-line estimation and
- provides an alternative model needed for the generalized forgetting which is used to make the adaptation robust.

An alternative treatment of prior knowledge expressed fully in terms of data properties is described in [110].

Bayesian structure estimation. The theory and algorithms for estimating the adequate model structure have reached an advanced state. At present:

- prior knowledge can be incorporated
- fine model structure can be estimated by correctly splitting multi-output models into a set of single-output ones
- control period can be estimated [15] together with other structure parameters.

These results are described in the excellent PhD thesis [10].

Advances in the control design. Introduction of the input reference signal as an analogy to the output reference (set point) into the LQ optimization proved to be useful in:

- removing a steady-state error in step response,
- making possible a smooth transition from the controller that follows an input reference (typically generated by a default controller) to a fully LQ optimal controller with stability guaranteed in the whole tuning range [60, 62].

Spline-based adaptive LQ hybrid controllers provide complement to the discrete-time controllers. They respect continuous-time evolution of the controlled system as well as the discrete-time nature of the controller. In comparison with the traditional solutions, they should reach higher control quality by filtering that reflects properties of involved signals. The discussed controllers have been simplified by avoiding unnecessary approximation of kernels in the underlying convolution model [39, 40].

Extensive testing of LQ adaptive controllers. Adaptive and non-adaptive LQ controllers have been implemented in an LQ toolbox for Matlab and Simulink. The implementation includes the original extensions like the discussed input reference or data dependent penalizations. The extensive tests performed with this toolbox and documented in [211, 95] help the user:

- to share our long term experience with capabilities and limitations of the adaptive controllers,
- to tune the controllers after their automatic pre-tuning [16, 175],
- to exploit the novel features that extend the applicability of the controllers.

Industrial self-tuners and autotuners. The application gap between standard three-term controllers (PID) and advanced but complex LQG adaptive controllers is world-wide filled by PID controllers with self-tuning or autotuning features. An innovative controller of this type has been developed. It exploits microcontroller technology applicable in industrial environment. It covers a variety of standard features as well as novel self-tuning control algorithm. [97].

3.2 On-Line Fault Detection with Non-Linear Models

Use of realistic models for on-line supervision of production processes increases significantly quality of fault detection and isolation (FDI) techniques. It calls, however, for a deeper understanding of the FDI problem, for development of adequate data processing techniques and software tools.

A conceptual Bayesian solution of FDI with several models has been proposed in [14, 11]. Unlike its predecessors, it underlines the need for modelling of the fault dynamics. It also proposes alternative ways how to cope with the excessive dimensionality connected with the optimal solution.

An advanced technique addressing the dimensionality problem for general estimation tasks is presented in [109]. Applying information geometry of nonlinear estimation, an approximate implementation of statistical tests has been proposed that requires only a finite-dimensional statistic of observed data to be stored. The new approach makes use of the fact that the log-likelihood (log-posterior) value is directly related to Kerridge inaccuracy of the empirical distribution of data relative to the theoretical, model-based, parameter-dependent distribution. The Kerridge inaccuracy, which would require knowledge of the complete empirical distribution (or a sufficient statistic for the particular model class), is approximated through the minimum Kullback-Leibler distance between the set of all distributions of data consistent with the statistic value and the theoretical distribution. Markov Chain Monte Carlo methods, such as the Metropolis-Hastings algorithm, were suggested to evaluate the minimum Kullback-Leibler distance. The new fault detection method has been used to develop a "smart" sensor validation algorithm that shows on-line the percentage of gross-error and frozen-sensor readings. The paper [108] outlining the new method was awarded the Best Paper Prize at the IFAC symposium on Fault Detection, Supervision and Safety for Technical Processes held in Hull, UK.

A novel Bayesian bootstrap filter has also been proposed for solving the FDI problems when underlying state-space model is non-linear and/or non-Gaussian. The filter is implemented into the FDI Matlab Toolbox [203, 13, 206, 204] that has been developed for testing of the FDI techniques within the Copernicus project CT94-0237. Extensive tests indicate that the filter compares favourably with other implemented method. The tests on

Simulink-generated data and real data from a pilot three-tank system were complemented by a test on real data from a heat exchanger [205].

3.3 Fast Parallel Computations

The application area of the adaptive signal processing, control and fault detection algorithms can be extended substantially by use of fast and parallel computation schemes [75]. Such algorithms can be directly used in low power or high performance industrial applications. This explains the significant effort we put in this direction. The results are following:

- A novel efficient FDI method has been proposed. It estimates in parallel a collection of regression models differing in the considered data history or adaptation rate. Recursively evaluated probabilities of respective models are sensitive indicators of changes of the transfer function describing the supervised system.

  The method has been integrated into the FDI toolbox running in the Matlab 5 environment for personal computers, workstations and Linux platforms. It can also be executed on the parallel 64-bit Alpha AXP accelerator [203].
- Fast parallel algorithms for identification of systems with unknown structure have been derived. It is important that they are robust with respect to weakly informative data [179].
- Fast parallel algorithms for adaptive control have been completed and implemented under Matlab 5 and on Alpha hardware [75].
- A library of fast identification algorithms working with fixed-point arithmetics has been implemented. It is compatible with DEC Alpha and transputer-based PC-acceleration adapters.
- A systolic recursive least square estimator (with inverse updating) has been derived. The estimator is robust with respect to weakly

informative data. It is well suited for adaptive model-based predictive controllers.

- A probabilistic analysis of fixed point algorithms has been proposed. It serves as a novel tool for design of parallel VLSI circuits for recursive identification and filtering. Researchers working on Esprit project 23544 “A High Speed Logarithmic Arithmetic Unit” recognized practical importance of this analysis and involved us into this running project.
- The program package ParaMat has been designed for on-line communication of Matlab with add-in transputer or Alpha boards. The package, which is compatible with the new Matlab 5.1 release, has been designed in versions for transputers, ISA Alpha boards, PCI alpha boards [74, 72, 76]. It can be used with Windows 95, Windows NT, or with Linux operating system.
- Rapid prototyping of fast and parallel algorithms has got an efficient support by automatic generation of the C code from Matlab scripts. The system developed is a port of commercial tool MATCOM (company MathTools, USA). Our port supports execution of the C code on Alpha hardware in Linux [71].
- Fast algorithms for peak detection and target locating for a Collision Avoidance Radar have been designed for use in a control system system of an automatically guided vehicle (AGV) [178]. Performance improvements in comparison with standard signal processing techniques were demonstrated.

Network-type Approaches in Statistical Decision Making

Bayesian statistical decision making (SDM) is a well developed methodology suitable for solving variety of estimation, prediction and control problems. Inherent high dimensionality [237] restricts application range of this approach. For this reason, we are searching for approximation methodologies which would help us to cross this barrier. Successes of artificial neural networks (NN) suggest us to adopt their underlying philosophy without loosing advantages of SDM. At general level, the problem was thoroughly inspected in [84, 82]. The final aim of coupling advantages of both paradigms is addressed gradually. We have started naturally with complex LQG controllers and controlled high order Markov chains with many states.

Possibilities of a systematic cooperation of several LQG controllers are inspected in [80]. Each controller tries to influence a projection of a long regression vector to a fixed orthogonal (wawelet-type) basis. The experiments revealed that independence of particular projections is probably more important than the orthogonality. Experiments are also important conceptually: it can be shown that adaptive systems have to be local approximators [77]. Thus, the desirable globality can only be reached by their – a priori determined – combination.

LQG adaptive controllers are mostly and successfully used nowadays. However, they face difficulties whenever the controlled process is non-linear or the range of inputs is restricted [35]. Adaptive predictors and controllers based on controlled Markov chains represent a promising alternative. They take above mentioned restrictions explicitly into account. Moreover, their Bayesian identification and control is conceptually simple. The processing includes just trivial algebraic operations and search over a finite set. However, dimensionality of the problem [34] prevents to exploit the superior ability to cope with any stationary non-linear stochastic digitized system. For beating the dimensionality, we are inspecting the following conceptual algorithm:

- data are aggregated to several low-dimensional spaces,
- controlled Markov chains are fitted to aggregated data so that the

best projection in the model space is gained [12],

- controllers are designed for each model,
- individual control actions proposed are "pooled" into the input applied to the system.

This line is elaborated in [78] where all key steps are resolved. Use of a novel fully probabilistic control design [156, 234] and improved pooling methodology make this approach feasible and promising. The selection of suitable aggregations seem to be the weakest step in the solution. The parametrization that combines detailed description of "significant" transition probabilities between states with global description of "less significant" ones is the direction we are researching at present.

Our effort to merge SDM and NN has started at the SDM side as it fits to our traditional know-how. We have been aware that our knowledge of NN part is weaker. The next part shows we are now much stronger.

3.4 Intelligent Systems for Prediction

Short term predictions are needed in a range of applications in different business sectors, industrial process control, quality control, demand (load, commodity) prediction, financial planning, etc. The study [201], classifying known approaches to the prediction task, focused our attention on NN and other techniques from so called soft computing [56]. Two forecasting schemes based on NN were studied in detail:

- a traditional feed-forward network with an improved multi-stage learning procedure,
- a radial-basis function network with an original adaptation of the centers.

The research has been extended to the field of fuzzy forcasting. A fuzzy predictor was designed which generates fuzzy rules from numerical data pairs, associates them into a Fuzzy Associative Memory bank and performs forecasting by applying a defuzzyfying method.

In [56], a reconstruction of the dynamics of time-series through delay coordinate embedding, determination of the geometrically nearest neighbours, and building local predictive mapping down the top singular value decomposition modes is also performed.

All these methods were successfully applied both to computer generated data series and real-life problems.

In the quest for efficiency of the developed systems, we focus on the integration of the learning capability of neural networks with the representational power of fuzzy sets. Evaluation of inputs and interpretation of outputs that reflect linguistic character of the experts' reasoning have been proposed in [57, 58, 148]. Alternatives to the simulation of the process dynamics have been outlined and use of neural networks with inherent dynamic behavior recommended. In [59], chaos theory and evolutionary methods have been applied to determination of a representative set of input indicators, for optimization of the NN topology and other system-design issues.

Combinations of soft-computing methods allow us to increase prediction accuracy. This – together with representation of knowledge in the decision-makers language – will increase the credibility of the methodology [202, 148].

3.5 Robust Decentralized Control of Large-Scale Systems

A new extension of a complexity reduced decentralized control design for uncertain symmetric composite systems has been achieved. It uses a Riccati equation approach. A class of nonlinear but nominally linear systems with identical subsystems, symmetric interconnections and arbitrary uncertainties is considered. The nominal part of the system is described by a constant state matrix with identical diagonal blocks and identical off-diagonal blocks.

Motivation for studying this class of systems can be found, for instance, when similar interacting subsystems operate in parallel. Flow splitting reactors with combined pre-cooling, electric power systems, industrial manipulators with several degrees of freedom or flexible structures may serve as practical examples.

The controller-observer designed for an auxiliary artificial uncertain system whose dimension equals to the dimension of a subsystem in the original system ensures the overall asymptotic stability. The extension includes arbitrary uncertainties both in subsystems and interconnections. The uncertainties are modelled as unknown time-varying functions with known norm bounds. The matching conditions are not needed. A sufficient condition of stability of such system and design based on the reduced order system has been found. The solution employs the structural properties of the considered class of systems and uses the Riccati equation approach by Petersen. The result leads to a significant reduction of dimensionality for systems composed of a large number of subsystems [4].

Further, a major progress has been achieved in the disturbance attenuation for interconnected uncertain dynamic systems using decentralized control with input delays. The gained controller reduces the effect of disturbances on the overall system to an acceptable level. The derivation supposes that the decomposition structure of disjoint subsystems is a priori specified. No matching conditions are necessary. Parameters are supposed bounded in norm. The controller design involves a construction of H_∞ local-state feedback controllers via the Riccati equation approach [5]. This control design procedure is an extension of the result [6] on H_∞ decentralized control design.

3.6 Data Processing in Radiation Protection

Radiation protection is an important and challenging area for development and applications of advanced data-processing techniques. We have solved the problem of detection of trends in background dose rate measurements [151]. For this, capabilities of Bayesian predictors were evaluated when data are poorly informative. Efficient algorithms have been developed and tested for a prompt monitoring in the Czech Early Warning Network and RODOS automatic run. The algorithms predict when a threshold level is likely to be crossed well before the level is actually reached. The rate of false alarms is kept very low so that the obligatory preventive actions related to suspicion of a radioactive release can be speeded up substantially.

The algorithms for judging the predictive capabilities form a part of the ABET toolbox and they are available together with corresponding C codes. These outcomes have been obtained within the RODOS project. In connection with this project, methodology and software tools for evaluation of radiation protection in design of nuclear power plants have been also examined [161, 163].

Radon and its daughter products are recognized as the main natural cause of irradiation danger. Appropriate counter-measures in dwellings are expensive. For this reason, it is necessary to concentrate them on such buildings where real danger does exist.

It has motivated studies of dynamic behaviour of such buildings with the help of the advanced data processing techniques like Kalman filters [215].

3.7 Estimation Tasks in Nuclear Medicine

The strength of the Bayesian estimation methodology becomes visible when a high estimation quality is required using a few uncertain data and a vague but non-trivial prior information. We have used our estimation and modelling art in order to contribute to reliable estimation of various quantities inspected in nuclear medicine. They are mostly related to the dynamics of accumulation/elimination of ^{131}I [52]. The research has reached advanced stage so that the resulting data processing is now practically tested in connection with the treatment of thyroid gland diseases.

Dynamic scintigraphic studies serve as an efficient non-invasive diagnostic method typically for inspecting patient's kidneys. A sequence of images in a single projection is recorded above patient who was administered by a pharmaceutical with a low-intensity radioactive marker. The gained data have to decomposed so that they reflect dynamics of individual physiological structures. This task is traditionally solved by factor analysis which, however, face non-uniqueness of the obtained decomposition. In [79] a completely novel efficient solution of this problem is proposed. Under clearly specified conditions, vertices are searched for in the space of suitably normalized data. The algorithm, called DIAMAX, finds the correct solution within a finite and practically acceptable time. Even experimental studies in which theoretical conditions are violated indicate good properties of the algorithm. DIAMAX applicability is much wider than the motivating application [83].

4 Department of Stochastic Informatics

Head of Department:

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Assistant:

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Marie Hušková	–	regression analysis, change point problem, non-parametric methods
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Jiří Michálek	–	analytical methods in stochastics, random processes, statistical inference in stochastic processes, signal theory and signal processing e-mail: michalek@utia.cas.cz

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Jan Šindelář	–	theory of complexity and its application in probability and statistics, alternative theories of data processing e-mail: sindelar@utia.cas.cz
Petr Tichavský	–	system and signal theory, in particular sinusoidal modelling and high-resolution spectral analysis e-mail: tichavsk@utia.cas.cz
Igor Vajda	–	information theory, mathematical statistics e-mail: vajda@utia.cas.cz
Jan Ámos Víšek	–	robust statistics, regression analysis, adaptive statistical methods, statistical computations e-mail: visek@utia.cas.cz
Petr Volf	–	survival analysis, nonparametric regression, smoothing methods, statistical reliability testing e-mail: volf@utia.cas.cz

Postgraduate Students:

Lucie Fialová	–	applied information theory
Martina Pavlicová	–	spectral theory of random processes.

Conferences:

Ten lectures, one of them invited, have been delivered at international conferences, including

> ISI – Stellite Meeting: Mathematical Statistics and its Applications to Biosciences, Rostock, Germany
>
> Conference on AI and soft computing, Banff, Canada
>
> Econometric Society European Meeting, Toulouse, France.

Grants and Projects:

M. Janžura: "Gibbs states and probabilistic methods in the theory of phase transitions" (GA ČR, 202/96/0731, 1996 – 1998).

M. Janžura: "Statistical distances of random fields" (GA AV ČR, A 1075601, 1996 – 1997).

J. Michálek: "Maximum likelihood principle and I-divergence" (GA ČR, 201/96/0415, 1996 – 1999).

I. Vajda: "Information-theoretic criteria of goodness-of-fit between data and probabilistic models" (GA AV ČR, A 1075709, 1997 – 1999)

I. Vajda: "Research on ATM", (COPERNICUS'94 — European Research Project 589, 1995 – 1997).

J. Á. Víšek: "Sensitivity analysis of robust identification of regression models" (GA AV ČR, A 207583, 1998 – 2000).

P. Tichavský: "Identification of nonstationary systems" (GA ČR, 102/97/0466, 1997 – 1999)

International Cooperation

Members of the Department participated in joint research with their colleagues from Universities in

- Chicago, USA (Prof. A. Nehorai)
- Los Angeles, USA (Prof. A. Swami)
- Baltimore, USA (Prof. A. Rukhin)
- Baltimore, USA (Prof. J. Šmíd)
- Freiburg, Germany (Prof. L. Rüschendorf)
- Rostock, Germany (Prof. F. Liese)
- Madrid, Spain (Prof. D. Morales, L. Pardo, M. Menedez)
- Extremadura, Spain (Prof. A. M. Rubio, F. Quintana, L. Z. Aguilar)
- Paris 7, France (Prof. F. Comets)
- Leuven, Belgium (Prof. E. van der Meulen)
- Stockholm, Sweden (Prof. T. Koski)
- Stockholm, Sweden (Dr. P. Händel)
- Budapest, Hungary (Prof. L. Györfi)
- Michigan, USA (Prof. V. Fabian, H. Koul)
- Wayne, USA (R. Z. Chasminskij)
- Vilnius, Lithuania (V. Paulauskas, A. Rachkauskas)
- Delft, Netherlands (Prof. J. van der Weide)
- Berlin, BRD (Prof. W. Römisch)
- Ascona, Switzerland (Prof. E. M. Ronchetti)
- London, U. K. (Prof. M. Landsbury)
- Madrid, Spain (Prof. E. Sentana)

- La Plata, Argentina (Prof. C. Muravchik)
- Linköping, Sweden (Prof. N. Bergman)
- Montpellier, France (Prof. A. Berlinet)
- Vienna, Austria (Prof. H.-P. Bernard)
- Milano, Italy (Prof. S. M. Savaresi)

The results of this cooperation are summarized in the published papers [23, 49, 47, 48, 131, 132, 147, 162, 184, 185, 186, 187, 188, 189, 208, 207, 209, 210] and in additional papers 11 accepted and 7 submitted.

University Courses

Fifteen courses on subjects related to the research field of the department were read.

Charles University — Faculty of Mathematics and Physics:
Probability and mathematical statistics, Statistics, Sequential and Bayesian methods (M. Hušková); Probability theory, Advanced parts of econometrics (P. Lachout).

Charles University — Faculty of Social Sciences:
Econometrics, Probability and mathematical statistics,
Statistics (J. Á. Víšek).

Czech Technical University — Faculty of Physical and Nuclear Engineering:
Random processes (J. Michálek), Information theory (I. Vajda); Statistical Analysis of Data (J. Á. Víšek); Stochastic systems (M. Janžura); Signal analysis (P. Tichavský)

Technical University Liberec:
Mathematical Statistics, Elements of probability theory (P. Volf).

As part of teaching activities at the above Universities, seventeen diploma projects and eleven doctoral theses were supervised, 3 habilitation theses refereed.

I. Vajda was a member of Scientific Boards of the Faculties of Electrical Engineering and of Physical and Nuclear Engineering.

Researchers of the Department were members of six different boards for defenses of doctoral theses at the Charles University and Czech Technical University.

Research Activities

The Department concentrates on mathematical research in the following areas.

a) Information in statistical experiments and optimal statistical decisions (estimation, testing, classification), with emphasis on maximum entropy, minimum divergence methods, and asymptotic theory.

b) Robust statistical procedures and their applications in various statistical environments, including adaptivity and self-organization. Regression analysis.

c) Statistical inference in random processes and random fields. Applications in stochastic optimization, change-point, optimum investment portfolios, and image and speech processing.

Altogether 38 papers have appeared during 1997. Eighteen others have been accepted for publication and 20 papers have been submitted.

Recent Results

4.1 Estimating Information

The mutual information possesses properties that make it an ideal measure of statistical dependence. Sadly, its use in data analysis remained limited as there existed no good nonparametric estimator for it. A solution to the estimation problem has now been found. It has been shown that it is possible to approximate the mutual information arbitrarily closely in probability by calculating relative frequencies on appropriate partitions. These appropriate partitions are characterised by the fact that local independence has been achieved on the rectangles of which they are made. This motivates an adaptive partitioning algorithm in which the partitioning on any rectangle is stopped as soon as a criterion for independence is locally satisfied.

A new algorithm for estimating the mutual information from multivariate data has been implemented. The bias and variance of this nonparametric estimator have been extensively studied. A comparison to parametric estimators (in the few cases when they are known) has been conducted. The results of the nonparametric estimator are simply excellent. Care has been taken in optimizing the algorithm. It now is remarkably fast: when compared to a straightforward implementation it is faster by more than two orders of magnitude.

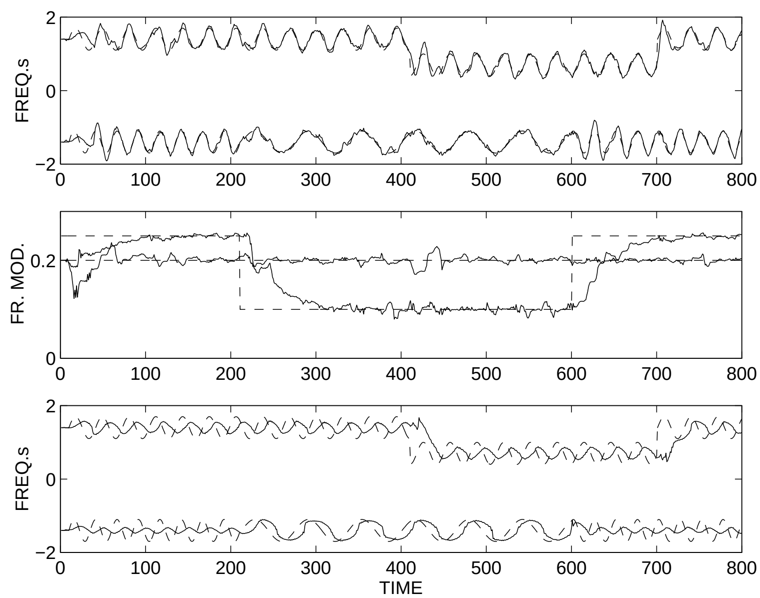
It has been shown that it is not true in general that gaussian distributions minimize the mutual information under the constraint of fixed correlations. A condition under which this is true has been identified.

New analytic expressions for multivariate differential entropies have been obtained. Incredibly enough, this corrects several (completely) wrong results which were published in the IEEE Transactions on Information Theory. Two estimators of the entropy have been compared. One of them, for which a new and fast algorithm has been implemented, has performed very nicely on the first series of simulations.

4.2 Recursive Estimation of Linearly or Harmonically Modulated Frequencies of Multiple Cisoids in Noise

Digital signals (time series) composed of a finite number of real or comple-valued sinusoids are encountered in a number of application such as radar, communications, control and biomedical engineering. Often it happens that parameters of the individual signal components, frequencies or magnitudes, slowly vary in time. The problem of adaptive estimation of these parameters (known as parameter tracking) has been intensively studied recently and several different algorithms were proposed, see e. g. [210] and the referencies therein. The algorithms perform relatively well if the estimated parameters, in particular frequencies, are time-varying in a random way, randomly up or down. However, if it is a-priori known that the estimated instantaneous frequencies are (piecewise) linear or harmonic (evolving like a sinusoid plus a constant), it is possible to utilize this information and improve the estimation. Signal with a linear frequency modulation are encountered for example in pulse compression radar systems, where the target for the radar is moving with an acceleration. Signal with a harmonic frequency modulation can be encountered in a coherent laser radar technology for remote sensing of vibrational characteristics of objects.

The above mentioned simple algorithms for sinusoidal parameters tracking, when applied to signals with linearly or harmonically modulated frequencies, exhibit a necessary delay of reaction, which is a price for ability of the algorithms to suppress an additive noise, that corrupts the data. In papers [207, 208], specialized algorithms for linearly or harmonically modulated frequencies were designed and tested, which eliminate the problem of the estimation delay. As a by-product, the proposed algorithms decompose the signals to individual components.



Performance of the latter algorithm is demonstrated on the following example. A complex-valued signal consisting of two components with unit amplitudes and additive white Gaussian noise with zero mean and variance 0.1 is considered. The estimated instantaneous frequencies are piecewise harmonically modulated, as shown in Figure 1. Correct frequencies and frequencies of the modulation are marked by dashed lines and estimates by full lines.

The first two diagrams demonstrate a good performance of the novel algorithm, the last diagram shows performance of a simple tracking algorithm.

4.3 New Statistics for Testing Hypotheses

The paper [147] deals with composite hypotheses in statistical models with i.i.d. observations and with arbitrary families dominated by σ-finite measures and parametrized by vector-valued $\theta \in \Theta$. If $\Theta \subset R^d$ and the hypothesis is of the form $\Theta_0 = \{h(\beta) : \beta \in B\}$ where $B \subset R^{d-d_0}$ is open and $1 \leq d_0 < d$, the classical is the Wilks (or generalized likelihood ratio) test using the statistics

$$L_n = 2n \left[\lambda_n(\hat{\theta}_n) - \lambda_n(h(\hat{\beta}_n))\right],$$

where $\lambda_n(\theta)$ is the loglikelihood function $n^{-1}(\ln f_\theta(X_1) + \cdots + \ln f_\theta(X_n))$ of the sample $X_1, \ldots, X_n$, and $\hat{\theta}_n$, $\hat{\beta}_n$ are the unrestricted and restricted maximum likelihood estimates of the true parameters $\theta_0 = h(\beta_0)$ and β_0. Another classical test is the Rao test using the statistics

$$R_n = n\, \delta_n(h(\hat{\beta}_n))\, I^{-1}_{h(\hat{\beta}_n)} \delta_n(h(\hat{\beta}_n))^t,$$

where $\delta_n(\theta)$ is the gradient of $\lambda_n(\theta)$ and I_θ is the Fisher information. In this paper are introduced the ϕ-divergence tests using the

ϕ-divergence statistics

$$D_{\phi n} = 2n\, D_\phi \left(f_{\hat\theta_n}, f_{h(\hat\beta_n)} \right),$$

where $D_\phi(f_\theta, f_{\theta *})$ denotes the ϕ-divergence of distributions with densities $f_\theta,\ f_{\theta^*}$. It is proved that for convex functions ϕ with the second derivative $\phi''(1) \neq 0$, the ϕ-divergence statistics have the same asymptotic $\chi^2_{d-d_0}$-distribution as the statistics L_n and R_n. Using the hypothesis $\mu = 3\sigma$ about the mean and variance of the normal family, it is shown that the power of the ϕ-divergence test of Θ_0 against the alternative $\Theta - \Theta_0$ can be essentially better than that of the Wilks and Rao tests of the same size. In fact, a relative efficiency the Hellinger test, using the Hellinger divergence statistics, was shown to be twice better than that of the Wilks test, and about 1/3 times better than that of the Rao test.

4.4 MCMC Estimates for Regression Models

The research concerned the development of methodology of general regression analysis. Methods of nonparametric regression, construction of nonlinear models, cases with multivariate inputs as well as generalized additive models have been considered. The methods of model selection have been examined especially from the point of view of their optimality (i. e. flexibility versus complexity of obtained models).

Two approaches have been studied: The Markov chain Monte Carlo (MCMC) approach has been adapted to case of multivariate regression models constructed from polynomial splines or other functional bases (e. g. radial basis functions). Such a multiparameter nonlinear optimization problem has been solved with the aid of a hybrid variant of Metropolis–Hastings algorithm. The optimal complexity of resulting models has been achieved by a convenient choice of prior distribution of the number of basal functions. In such a way, also a choice of input variables has been controlled ([189, 185]). A similar has been developed for in the case of nonparametrized Cox model.

As a deterministic alternative to randomized MCMC method, an incremental procedure of model construction has been developed. The idea (similar to that of sequential procedures CART or MARS) consists in iterative addition of functional units (e. g. splines). The selection of splines requires the specification of splines' locations and parameters. The decision about location of a new unit has been based on a change-point detection method. The optimal complexity of model has then been controlled with the aid of penalty criteria (variants of Akaike's IC) [187].

Both approaches have been applied to analysis of series of spacecraft engineering data (in the framework of colaboration with NASA/GSFC center in Greenbelt, USA). One type of data was a time series of calibration coefficients from sensors flown on spacecrafts. The series has been smoothed, its behaviour modelled and predicted. A second type of data presented a system with multiple inputs. Namely, behaviour of a battery (located on an satellite) has been modelled from in-orbit measurements. A local (in the time) nonlinear model has been derived. Its long-term changes then corresponded to degradation of battery [188]. We have also studied the information content of other variables (temperature, pressure) in local models based on current, change and voltage data.

5 Department of Econometrics

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Secretary:

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Hana Havlová	–	Statistical analysis of a true random generator.
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Zdeněk Tůma	–	Macroeconomics, macroeconometrics. e-mail: ztuma@patria.cz
František Včelař	–	Generalized choice model and Arrow problem in many–valued logical environment.

The Department concentrates on mathematical and economical research in the following areas:

- Stochastic economics, econometries and econometrics modelling,
- uncertainty processing in expert systems,
- stochastic differential equations with application to capital markets,
- stochastic optimization.

Grants and Projects:

- A. Derviz: *Stochastic General Equilibrium Theory of Emerging Capital Markets* (Grant GA AV No. A 8085701)

- V. Kaňková: *Sensitivity analysis, Approximations and Empirical Estimates in Multistage Stochastic Programming* (Grant GA AV No. A 1075502)
- M. Mareš: *Fuzzy Set Theoretical Models of Cooperative Behaviour of Econommic Subject.* (Grant GA ČR No. 402/96/0414)
- K. Sladký: *Time Dependent Stochastic Systems*. (Grant GA AV No. A 2075506)
- K. Sladký: *Complex Economic Systems and Decision Making under Uncertainty*. (Grant GA ČR No. 402/96/0420)
- M. Vošvrda: *Information Asymmetries on Capital Markets Emergingin Transition Countries, the Case of the Czech Capital Market*. (PHARE ACE Project No P95–2014–R)

University Courses:

- *University of Economics, Prague*
    - J. Kodera - Capital Markets
- *Faculty of Social Sciences of the Charles University :*
    - A. Derviz - International Finance A1
    - V. Kaňková - Decision in Economy – Deterministic Optimization
    - M. Mareš - Game Theory and Capital Markets

- K. Sladký - Stochastic Processes in Economy
- Z. Tůma - Macroeconomics I
- F. Včelař - Probability Theory and Mathematical Statistics
- M. Vošvrda - Probability Theory and Mathematical Statistics
- M. Vošvrda - Econometrics
- M. Vošvrda - Capital Markets

- *Faculty of Electrical Engineering of the Czech Technical University:*
  - M. Mareš - Coalition game theory (doctoral study)

Our visitors:

- Prof. Nico van Dijk (University of Amsterdam)
- Prof. Ulrich Rieder (University of Ulm)
- Ing. Jaroslav Vokoun (Institute of Economic of the Slovak Academy of Sciences)
- Dr. Rita Ribeiro (University of Lisabon)
- Dr. Igor Chernenko (University of Duisburg)
- Ph.D. Gene Hsin Chang (University of Toledo)

Diploma and Doctoral projects:
Diploma:

- Faculty of Mathematics and Physics of the Charles University (supervisor V. Kaňková - 2)
- Faculty of Social Sciences of the Charles University (supervisor M. Vošvrda - 3)
- Faculty of Nuclear Physics and Engineering of the Czech Technical University (supervisor Vošvrda - 1)

Doctoral:

- Faculty of Social Sciences of the Charles University (supervisor M. Vošvrda - 1)
- University of Economics, Prague (supervisor Vošvrda - 1)

Conferences Participation:

1. GAMM/IFIP–Workshop and Tutorial on Stochastic Optimization, Lambrecht (Germany) 1997 (V. Kaňková)
2. Second GAMM Workshop: Stochastische Modelle und Steuerung, Dresden 1997 (V. KaňkováÖ, K. Sladký)
3. International Conference on Mathematical Programming, Lausanne (Switzerland) 1997 (V. Kaňková)
4. Symposium on Operations Research 1997, Jena (Germany) 1997 (K. Sladký)

5. Mathematical Methods in Economics'97, Ostrava 1997 (V. Kaňková, K. Sladký)

6. Econometric Day '97 (V. Kaňková, K. Sladký, Z. Tůma, M. Vošvrda)

7. Quantitative Methods in Finance 1997, Sydney-Cairns-Canberra (Australia) 1997 (A. Derviz)

8. Real Effects of Nominal Exchange Rate Movements, Athens (Greece) 1997 (A. Derviz)

Members of the Department participated in joint research with their collegues from University of Amsterdam (Department of Economic Sciences and Econometrics), University of Cambridge, University of Bath, London Business School and Federal University of Rio de Janeiro.

Three members of the Department (J. Špitálský, Z. Tůma, and M. Vošvrda), were promoted fellows of the Czech Econometric Society.

M. Vošvrda and E. Dostálová are editors of the Bulletin of the Czech Econometrics Society.

M. Mareš is Tresaurer of the Czech Society for Cybernetics and Informatics and Member of the American Mathematical Society and Member of the Academic Board of the Academy of Sciences of the Czech Republic.

K. Sladký is Managing Editor of Journal Kybernetika.

J. Kodera, K. Sladký, and M. Vošvrda have become members of the Economic Sciences Division of the Grant Agency of the Czech Republic and Z. Tůma is chairman of this division (M. Vošvrda was chairmen until May 1997).

We have also participated in a TEMPUS program for forming lectures on Capital Markets at Universities in Europe (Aberystwyth - Wales).

5.1 Fuzzy Coalition Games

The classical theory of coalition games is focused on the negotiation games is focused on the negotiation process and its results in the behavioral and economic situations. It is based on the assumption that the agents (players) entering the negotiations exactly know the expected total pay-offs of very coalition and, consequently, their own profits following from the negotiated cooperation. This deterministic knowledge means also deterministic validity of important properties of the game, like its superadditivity or convexity, and crisp mathematical form of possible solutions like the core or value of the game.

The assumption of the full knowledge about the expected results of the game is not realistic. In usual situations the players, starting the negotiation process, have only very vague idea about the final pay-offs which are to be distributed among the members of coalitions. This vagueness of the input data leads to analogous vagueness connected with the validity of important properties and the shape of the possible solutions.

The vague expectation of the game results can be formally modelled by fuzzy numbers and fuzzy sets. The general result about the algebraic operations with fuzzy numbers, derived in the previous years, were used to derive general properties of the fuzzy coalition games.

The basic concept used in the mathematical models of vague negotiations is the concept of fuzzy extension of a deterministic coalition game. It means that the crisp numbers characterizing the expected incomes of coalitions are completed by other, more or less possible values. Fuzzy numbers constructed in this way are processed by usual methods of the analysis of the coalition forming.

It was shown that the possible validity of important properties like superadditivity depends on their deterministic fulfillment. Moreover, if there exists a non-empty core in the original deterministic game then there exists its fuzzy analogy in the fuzzy coalition game. However it was shown that some concepts of the deterministic game, like domination of imputations, cannot be mechanically transmitted into the fuzzy environment and their reformulation is subjected to a deeper analysis of the structures and relations in the fuzzy games. Similarly, the solution of the games without side-payments (which is based on the set theoretical analysis of the game), and the solution of game with side-payments (which is based on the numerical relations in the game) do not keep the strong mutual dependence which exists in the deterministic case. They represent relatively independent structures of relations between the fuzzy pay-offs and are connected with rather modified possibilities of realization of some (name, large) coalitions. The results were summarized in [126] and in further manuscripts accepted for publication in 1998.

5.2 Generator of Fuzzy Quantities

- the transformation principle [136] allows to modify the shape of fuzzy quantities under processing and/or the triangular norm we are working with; consequently, the equivalence of several shape classes is proved (linear fuzzy numbers, bell shaped fuzzy numbers, etc.), and several well known results for triangular fuzzy numbers can be extended to another shapes; similarly, we can generalize the results based on the Lukasiewicz t-norm for any nilpotent t-norm and those based on product t-norm for any strict t-norm;

- arithmetics of fuzzy numbers based on triangular norms [137] brings new results especially for the addition of fuzzy intervals when an exact output should be computed;

- characterization and representation of fuzzy possibility measures is discussed in [135]; an important role is played by possibility measures fulfilling the countable chain condition; some of them are characterized as essential suprema of the corresponding possibility distribution with respect to some sigma-additive measure; it is a conjecture still that these are the only possibility measure with above property.

5.3 Dynamic Economic Systems Under Uncertainty: Multistage stochastic and dynamic programming approaches

More sophisticated approaches for handling dynamic models under uncertainty are often based on the two closely connected areas of stochastic optimization: the multistage stochastic programming and stochastic control (dynamic programming). Such models can be investigated over finite or infinite time horizon in discrete- or continuous-time setting.

Multistage stochastic programming problems cover an essential part of above mentioned problems if a finite time horizon is considered. In particular, the multistage stochastic programming problems correspond to real-life models that can be suitably treated in discrete-time with respect to a given finite time horizon and, simultaneously, in which it is necessary to determine a solution at every specified time point. According to this fact it is mostly suitable to decompose the multistage problem to the individual time points. The new problems are parametric ones, there exists a close relationship among them. Consequently, to investigate the multistage problems it is suitable to investigate the decomposed problems with the corresponding intermediate relationships.

The investigation of the relationship among the individual decomposed problems started in [89]. To this end, two–stage stochastic programming problems were introduced and investigated in a generalized form that corresponds to the individual decomposed problems. Similar approach was also employed for the study of the statistical estimates in case of time dependent problems [92]. The behaviour of the decomposed problems depend on the behaviour of the corresponding multifunctions [91].

Models of stochastic programming are rather complicated both from the theoretical and applicational points of view. Consequently, every possible restriction is very useful. In [93] problems with s–dimensional ($s \geq 1$) random elements are introduced that can be reduced (at least from the mathematical point of view) to the one–dimensional random element. The investigation in stochastic programming can be completed by [90], where ε–approximate solution is suggested for the case where only moment information is available.

Multistage stochastic programs are in their nature very similar to multistage stochastic control problems. We get the “most simple" case of a dynamic optimization problem supposing that the goal function of the considered problem is separable, and that the “future development" of the considered system depends only on its “current state" and the “decision taken". From the above facts it is clear that the multistage recourse models have a natural counterpart in discrete-time stochastic optimal control problems, however, the concept of solution is somewhat different in both models. On the contrary to multistage recourse models, most of the motivation for the research on stochastic control problems come from a class of applications where it is the decision rule that is of interest; hence, the insistance of finding a rule that depends on the observed state and not on the information we may infer about the underlying stochastic phenomena.

This topic was studied in [94]. In addition to the general formulation, attention was focused also on numerical aspects of the solution as well as on evaluation (sub)optimal solution using some non-traditional (i.e. risk sensitive) utility functions. Also under some general assumption some constraints were introducted that enable to formulate the problem as a linear programming problem. Special attention was also focused to the case when the considered utility function is multiplicative.

A systematic attention was also payed to the models of stochastic dynamic programming and Markov reward models. Particularly, we considered the *generalized dynamic reward structures*, in which the *transition probability* is generalized to an arbitrary *matrix with nonnegative elements* if the discrete-time models are considered. Similarly, in the continuous-time setting the *transition rate matrix* is generalized to an arbitrary *matrix with nonnegative off-diagonal elements*. One natural application of these models being of substantial practical interest are so-called *input-output models in economic analysis*.

In this direction we investigated extensions of the classical technique of uniformization as well as of the so-called overtaking optimality that were investigated only for purely stochastic systems in the literature. Overtaking optimality was introduced and successfully applied in many economic models. Unfortunately, overtaking optimality need not be a reasonable optimality criteria in stochastic dynamic programming problems, i.e. it may happen that no overtaking optimal policy exists for a Markov decision chain. Some sufficient conditions for existence of a stationary overtaking optimal policy can be found in the literature.

In [216] extensions of the classical technique of uniformization to continuous-time dynamic systems with generators given by arbitrary reducible matrices with nonnegative off-diagonal entries were investigated. The obtained results are of computational and theoretical interest. In [183] we extend the results concerning existence of overtaking optimality for stochastic systems to more general dynamic nonnegative systems, i.e. to dynamic programming models where transition probability matrices are replaced by nonnegative matrices.

5.4 Stochastic Control Application to International Markets

The earlier developed model of consumption and portfolio adjustment under diffusion uncertainty, based on a stochastic maximum principle in the adjoint process form [28], was applied to the problem of asset price formation under an independent exchange rate risk [29]. The solution of this problem consists in a direct application of the shadow price results of the maximum principle to equilibria in the investment goods markets of an open economy. It turns out that only the volatility term of the exchange rate dynamic is present in the pricing equations - a result similar to the well known ones in the traditional consumption-based capital asset pricing model. Similar methods were used by the author to obtain results on international valuation of domestic financial intermediaries, conducted for the Czech National Bank.

5.5 A Bivariate Integral Control Mechanism Model of Household Consumption

On the basis of nonstochastic steady-state relationships implied by the corresponding economic theory, stochastic disequilibrium relationships among relevant variables can be developed such that these relationships will in steady-state simplify to the nonstochastic steady-state relationships. Based on this methodology, proceeding from properties of cointegrated variables, a theoretic model of household consumption, applicable to existing Czech data, was derived. This extension of an Error Correction Mechanism model and of an Integral Control Mechanism model presents household consumption in the form of a Bivariate Integral Control Mechanism model. In this model, household wealth as a determinant of household consumption is simultaneously proxied by two integral variables, liquidity holdings and savings. Based on the model, short- and long- run consumption predictions as well as the equilibrium relations between consumption, liquidity holdings, savings, and disposable income can be assessed [235].

5.6 Information and Capital Markets

A description of the Capital Market in the Czech Republic is introduced in [100]. A description of the Slovak Capital Market is introduced by Vokoun J. in [226]. For analyzing entrepreneurial behavior on capital markets were chosen four Stock Exchanges (Amsterdam, Lisbon, Prague, and Bratislava). The behavior was researched based on alpha, beta and specific risk Z. The detailed description of this method is described in Vosvrda M. [225]. For comparison we observed two stock exchange which belong to the EU and two which do not. We analyzed the following members:

1. Amsterdam Stock Exchange (ASE) representing stable stock exchange with long tradition.

2. Lisbon Stock Exchange (LSE) representing stock exchange of the developing country and at the same time belonging to the EU.

3. Prague Stock Exchange (PSE) representing stock exchange with went through the ownership transformation and is not belonging to the EU (for detailed information please see in [100]

4. Bratislava Stock Exchange (BSE) representing stock exchange which phases the ownership transformation and is not belonging to the EU

   From the research is possible to conjecture that

   - the ASE has very low specific risk, the BSE has very high specific risk, and the LSE, and the PSE have very similar level of the specific risk,
   - the behavior of the parameters betas finds out that all analyzed stock exchanges have standard behavior,
   - all stocks are defensive and are correlated to market return,

- by Treynor's performance index, the ASE is very close to the equilibrium market value, and the PSE is very far from the equilibrium market value.

For detailed description of the results please see in [225].

5.7 A Market Structure Efficiency

A measure of an economic efficiency through a price ergodicity was introduced to cover a variety of a market structures in both deterministic and stochastic framework. The evaluation of both upper and lower boundaries of inflation and an expectations-augment Phillips curve was estimated by linear regression. It was shown that standard economies have known a shape of an expectations-augment Phillips curve. Moreover, it was also shown that economies with an elastic price level but a very poor stabilization power of economy have an opposite slope of an expectations-augment Phillips curve. From a slope of the regression line between an inflation level and deviations of the output from the potential output, it can be argued on a position of economy from a point of view an efficiency of a market structure as a criteria of market economy [227].

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Grants and Projects

- J. Novovičová, “Simultaneous feature selection and classifier design in statistical pattern recognition”
  Grant Agency of the Academy of Sciences of the Czech Republic; No. A2075608
- P. Pudil, “Multidisciplinary approaches to support of decision-making in economics and management”
  Grant of the Ministry of Education (jointly with the Faculty of Management, University of South Bohemia); No. VS96063
- P. Pudil, “Non-classical approaches to decision-making”
  Grant Agency of the Czech Republic; No. 402/97/1242
- J. Grim, “Probabilistic neural networks”
  Grant Agency of the Academy of Sciences of the Czech Republic; No. A2075703
- M. Haindl, “VIRTUOUS - Autonomous Acquisition of Virtual Reality Models from Real World Scenes”
  European Union project INCO Copernicus; No. 960174

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  Somol P.: “Algorithms and Program Implementation for Solving Problems of High Dimensionality of Input Data in Statistical Pattern Recognition”
  Supervisor: P. Pudil
- Faculty of Mechatronics, Technical University, Liberec
  Vrňata R.: “Knowledge-based System for Solving Feature Selection Problems in Statistical Pattern Recognition”
  Supervisor: P. Pudil

- Faculty of Nuclear and Physical Engineering, Czech Technical University
  Vejvalková J. : "Integration of Expert Knowledge in the Probabilistic Expert Systems"
  Supervisor: J. Grim

- Faculty of Mathematics, Charles University
  Žid P.: "Image Segmentation in Virtual Reality Acquisition Applications"
  Supervisor: M. Haindl

- Faculty of Mathematics, Charles University
  Havlíček V.: "Texture Synthesis"
  Supervisor: M. Haindl

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Conferences

The department organized jointly with TC1 IAPR the STIPR'97 Workshop (The First International Workshop on Statistical Techniques in Pattern Recognition) held in Prague, June 9-11. About 50 researchers from many countries participated at the workshop. The research results of the department members have been presented at several international conferences including:

- *STIPR'97*, 1st IAPR TC1 Workshop on Statistical Techniques in Pattern Recognition
  Prague, Czech Republic, 1997, cf. [41], [171], [38].
- *9th International Conference on Image Analysis and Processing*
  Florence, Italy, September 15 - 20, 1997,[42].

Research Results

The scope of the Department of Pattern Recognition activities covers pattern recognition, with emphasis on statistical feature selection, probabilistic neural networks, modelling of random fields for scene interpretation and applications in economics and medicine. In all these areas the group members enjoy an international reputation expressed by scientific awards and memberships in governing bodies of international organizations.

6.1 Statistical Pattern Recognition

The choice of the optimal methods for selection of feature variables in statistical pattern recognition depends on a number of conditions, like the aim of dimensionality reduction, the original dimensionality of input data, the level of apriori knowledge of underlying probability structure, the size of the training sets, etc. With the aim to ease the situation, the consulting or expert system is currently developed which should guide a less experienced user through the method included into the package [171]. The core of the package will be formed by the novel methods we have developed ourselves i.e. the floating search methods and the methods based on finite mixtures.

A new approach to feature selection has been developed. It is based on the assumption that the classes are modelled as modified mixtures of normal distributions with latent structure, which can be controlled by introducing the binary parameters [157]. The method is suitable especially if the underlying distributions of some or all given classes are multimodal or they conceal the existence of subpopulations. It allows to develop two feature selection methods: "approximation" method determines those features which are best in the sense of minimizing the mixture of Kullback-Leibler distances between true and postulated class conditional probability density functions; "divergence" method identifies those features that are most useful, in the sense of maximizing the Kullback divergence in describing differences between two possible classes. Our proposal for feature selection has the following characteristics: (i) the uknown model parameters are estimated from the training data sets by maximizing the corresponding likelihood function using EM algorithm; (ii) no search procedure is required for identification of the most important feature variables and thus for facilitation of the dimensionality reduction; (iii) reduces also the complexity of the corresponding Bayes decision making.

Initialization of the EM algorithm for use in normal mixture modeling methods may have a significant influence not only on the convergence, but also on the quality of achieved results. The behavior of EM algorithm on small sample size sets was tested using a real world data and different approaches to initialization of the EM algorithm [190]. None of the investigated methods has been found to be optimal for all the conditions. When time saving is the goal, the Dogs & Rabbits strategy gives the best results in most cases.

6.2 Probabilistic Neural Networks

The research of probabilistic neural networks (cf. grant of the Academy of Sciences No. A2075703) has been oriented on some basic theoretical aspects of the design of multilayer feedforward neural networks. The approach is based on approximating unknown probability distributions by finite mixtures in the framework of statistical decision-making. The components of mixtures correspond to neurons which transform the decision problem between consecutive layers. It has been shown [212] that a special type of transforms preserves the underlying decision information and simplifies the input structure in the sense that it minimizes the entropy in the class of all information-preserving transformations. Such transformation need not be unique, under some assumptions it may be any minimal sufficient statistics.

The design of multilayer structures is based on repeated maximum-likelihood estimation of finite distribution mixtures by means of EM algorithm. In this connection the recently discussed mixture of experts architecture of neural networks has been shown to be interpretable as a special case of conditional expectation formula for finite mixtures [38].

A weak point of the probabilistic approach to neural networks is the tacitly assumed complete interconnection of component densities of mixtures with all input variables (neurons) of the preceding layer. The complete interconnection property of probabilistic neural networks arises from the very basic paradigma of probabilistic description but, on the other hand, such a structural "rigidity" is unnatural from the point of view of biological neural systems. We proposed [37] a new approach to structural optimization of the probabilistic neural networks based on maximum-likelihood criterion - without leaving the exact framework of probability theory. The method makes use of an idea originally designed for multivariate pattern recognition. It is based on finite mixtures with factorizable components including binary structural parameters. By means of a special "background" substitution technique the computation of statistically correct a posteriori probabilities can be reduced to different subspaces and, for the same reason, the receptive fields of corresponding neurons can be confined to arbitrary subsets of input variables.

6.3 Range Image Segmentation

Two novel range image segmentation algorithms were developed. The first image segmentation algorithm [42] is based on a recursive causal adaptive regression model prediction for detecting range image step discontinuities which are present at object face borders. The second segmentation algorithm [44], [43] is based on a combination of recursive adaptive regression model prediction for detecting range image step discontinuities and of a region growing on surface lines. The algorithm assumes scene objects with planar surfaces but more robust on noisy range data while keeping the numerical efficiency of the former method.

6.4 Image Data Reconstruction

A new scratch image reconstruction algorithm was published in [41]. This method does not assume any knowledge of reconstructed data, it uses available information from failed data elements surrounding due to spectral and spatial correlation in the multidimensional image data space.

The method is fully adaptive, numerically robust but still with moderate computational complexity. Experimental results on artificially removed image data reconstruction show superiority of the method over previously published ones.

7 Department of Image Processing

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Grants and Projects:

- J. Flusser - Image information processing in astronomy and astrophysics (Grant Agency of the Czech Republic, No. 205/95/0293 – jointly with the Astronomical Institute)

- J. Flusser - Recognition of radiometrically degraded digital images by the method of invariants (Grant Agency of the Czech Republic, No. 102/96/1694)

- D. Klimešová - Contextual methods of feature-based image classification (Grant Agency of the Czech Republic, No. 102/95/1295)

- S. Saic - 3D supercomputer modeling and visualization of rigid particles motion in viscous fluid (Grant Agency of the Czech Republic, No.102/96/0419 - jointly with Faculty of Science of Charles University)
- T. Suk - 3D shape reconstruction from intensity images (Grant Agency of the Czech Republic, No. 102/95/1378 – jointly with the Czech Technical University, Faculty of Electrical Engineering)
- J. Flusser - Computer Aided Fractography (Grant Agency of the Czech Republic, No. 106/97/0827 – jointly with the Faculty of Nuclear Sciences and Physical Engineering CTU)

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- Jaroslav Kautsky, Flinders University of South Australia, Adelaide, Australia
- Gabriela Peters, Institute of Neuroinformatics, Ruhr University, Bochum, Germany

The research activity is focused on the following areas:

- theory of the invariants
- recognition of distorted images and patterns
- texture and context analysis
- multisource and multitemporal data analysis
- image restoration
- applications in remote sensing, astronomy, medicine, archaeology, geodesy and geophysics

7.1 Multichannel Blind Deconvolution

In many science and engineering applications due to the imperfections in real imaging process the observed image is just a degraded version of the original image. These degradations are mainly caused by blur and noise. Usually this degradation is modeled by a convolution of the original image with linear shift invariant point spread function.

The goal of the image restoration is to obtain an estimate of the original image. This estimate is usually called *restored image*. The basic approach to this problem assumes a priori knowledge of the point spread function and some parameters of the noise. But this assumptions may not be met in practice.

In blind image restoration the restoration algorithms do not require the knowledge of the blur. Only partial information such as nonegativity, known finite support or symetry is required instead. Multiply blurred images are available in many applications. Examples of such a sensor ”diversity” include remote sensing, where the same scene may be observed at different time instants through a time varying inhomogeneous medium such as the atmosphere; electron microscopy, where the micrograph of the same specimen may be acquired at several different focus settings; or broadband imaging through a fixed medium which has a different transfer function at different frequencies. In this case we talk about *multichannel blind deconvolution*.

In the typical case the methods are based on minimizing of the following functional:

$$J(\hat{f},\hat{h}_i) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\sum_{\forall i}\|g_i(x,y)-\hat{f}(x,y)*\hat{h}_i(x,y)\|dxdy+J_1(\hat{f},\hat{h}_i)$$

The functional J_1 represents the conditions the estimate of the image and of the point spread functions must satisfy. This can prevent the trivial solution (h_i are the dirac functions) and also reduces the ambiguity of the solution. Usually the methods assume some statistical presumptions about the image and the blurs and solve this functional on statistical basis via maximum likelihood approach. The drawback of these methods is their heavy computational burden.

We developed an algorithm that is computationaly efficient and does not need any statistical presumptions about the image. Also *a priori* knowledge can be very easily incorporated. The idea is based on the iterative algorithm first reported by Ayers and Dainty. We have extended the original algorithm for the case of multiply blured image and also improved its convergence properties. The extension for multichannel deconvolution was done by introducing a 3D representation of the blured image. Convergence properties were improved by using an iterative Wiener filter instead of ordinary one. According to the numerical experiments the developed method gives good results.

7.2 Significant Point Detection in Multiframe Images

Detection of significant points in the image is the first step in image registration, image fusion, time-sequence analysis and in many other tasks, which are developed nowadays. Significant points (SP) are salient points which are easy to identify in the image, like corners, line intersections, etc.

The multiframe version of the SP detection works with two or more images of the same scene. Results of multiframe SP detection shouldn't be affected by various kinds of degradations (geometric as well as radiometric), which are introduced into the image during its acquisition by such factors as imaging geometry, motion of the scene, wrong focus, sensor errors, etc. Sets of points detected in all frames ought to be identical. These two demands, which are posed on the SP detection methods, are called the condition of repeatability. An applicability of methods depends on their ability to fulfil this condition under different kinds of present degradations. It is difficult to handle all types of degradations at once. Restrictions are often made about the type of degradation introduced during an acquisition.

We assume that the individual frames may be rotated and shifted with respect to one another, they may be degraded by a linear shift-invariant blur and that an additive zero-mean noise may be present. Under these conditions it is impossible to achieve identical point sets in different frames. The condition of repeatability is weakened to the point sets overlap of at least 50 %, which is, however, sufficient in most applications.

SP detectors can be divided into two groups. The first of them uses directly the grey-level information for SP detection. The second one detects significant points using the output of the edge detector, ran on the original image.

We propose parametrical SP detector for the multiframe case. Our parametrical approach allows handling differently blurred images. Points belonging to two edges with an angle about $\pi/2$ in between them are understood as significant points. The probable positions of edges P and the cost function C, based on the smoothness of the image, are computed from the acquired images. Significant points are detected using P and C functions.

This research has been done in cooperation with the visitors from Institut für Neuroinformatik, Ruhr-University, Bochum, Germany and from The Flinders University, Adelaide, South Australia.

7.3 An Invariant Approach to Degraded Image Analysis

Analysis and interpretation of an image which was acquired by a real (i.e. non-ideal) imaging system is a key problem in many application areas such as remote sensing, astronomy and medicine. Since real imaging systems as well as imaging conditions are usually imperfect, an observed image represents only a degraded version of the original scene. Various kinds of degradations (geometric as well as radiometric) are introduced into the image during the acquisition by such factors as imaging geometry, lens aberration, wrong focus, motion of the scene, systematic and random sensor errors, etc.

In the general case, the relation between ideal image $f(x, y)$ and observed image $g(x, y)$ is described as $g = \mathcal{D}(f)$, where $\mathcal{D}$ is a degradation operator. In the case of a linear shift-invariant imaging system, $\mathcal{D}$ is realized as

$$g(\tau(x, y)) = (f * h)(x, y) + n(x, y),$$

where $h(x, y)$ is the point-spread function (PSF) of the system, $n(x, y)$ is an additive random noise, τ is a transform of spatial coordinates due to projective imaging geometry and $*$ denotes a 2-D convolution. Knowing the image $g(x, y)$, our objective is to analyze the scene on the image $f(x, y)$.

There are basically two different approaches to degraded image analysis: blind restoration and direct analysis.

Direct analysis of a degraded image is based on the following idea: in many cases, one does not need to know the whole original image, one only needs for instance to localize or recognize some objects on it (typical examples are matching of a template against a blurred aerial image or recognition of blurred characters). In such cases, only a knowledge of some representation of the objects is sufficient. However, such a representation should be independent of the imaging system and should really describe the original image, not the degraded one.

We derived two sets of the so-called *Blur Invariants* which are based on image moments in the spatial domain and tangent of the Fourier transform phase in the spectral domain, respectively. Their definition, proof of invariance and applications to remote sensing and signal classification can be found in [32] and [31].

This work has been supported by the grant No.102/96/1694 of the Grant Agency of the Czech Republic.

7.4 3-D Supercomputer Modeling and Visualization of Rigid Particles Motion in Viscous Fluid

Modeling of structures around a rotating inclusion is important for study of synkinematic creation of porphyroblasts and porphyroclast that are used as shear sense indicators in structural geology. To understand the creation of the microstructures, structural geology use numerical or analogue modeling of behavior of rigid objects embedded in a viscous matrix. Numerical models are based on mechanics of continua and with more or less accuracy describe the motion of a rigid body and/or a flow around it. In our approach to the modeling and visualization of the motion of a rigid body we used Jeffery model that enable numerical modeling of the flow around a rigid ellipsoidal inclusion. Jeffery model is not restricted to the simple shear only but other and more complex types of flow are possible: simple shear, pure shear, axial flattening, any combination of them, and in general any homogeneous flow given by means of the velocity gradient tensor.

The flow around a rotating inclusion may be modeled if we solve simultaneously the equations for the inclusion rotation and the equations for the velocity field. The key point for solution of this equations is an efficient numerical evaluation of elliptic integrals . We developed such a procedure. Examples of modeling were visualized by MATLAB and animation sequences were created.

This research has been done jointly with Faculty of Science of Charles University and supported by the grant No.102/96/0419 of the Grant Agency of the Czech Republic.

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