ACTIVITY REPORT '99

GENERAL

Institute of Information Theory and Automation is a research institute of the Academy of Sciences of the Czech Republic. It is concerned with the development of control, information and computer sciences including in particular system theory and random processes from the point of view of mathematical modelling, decision making, automatic control and signal processing.

This report gives an overview of our research activities in 1999. It is of course not possible 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.

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 Radiotechnics 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 more than 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. It regularly organizes the Prague Conferences on Information Theory as well as other events sponsored by the Interna-

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tional Federation of Automatic Control (IFAC), International Federation on 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 essentially contributes to the activities of the Czech Society of Cybernetics and Informatics.

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, Incs. 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 coorganized the

- Workshop on Conditional-Independent Structures and Graphical Models, helt in Toronto in 1999.

and participated in the organisation of numerous other conferences.
Among others, the Institute is an organizer or coorganizer of

- International Conference IFAC ROCOND 2000 helt in Prague 2000.

- 18th Conference on Mathematical Methods in Economics, Prague 2000.

- International Workshop "Cybernetics and Informatics Eurodays: Young Generation Viewpoint", Mariánská 2000.

- Research Kitchen HSSS, Třešť 2000.

In 1999 the Institute celebrated 40 years of its existence. The seminar organized in this occasion in January was a pleasant opportunity for the members of the Institute, their former colleagues and friends from other institutions to meet and remember the years of their cooperation in the research and its support.

During four decades of its existence ÚTIA became a well known centre of research in theoretical cybernetics and related branches of science. Special attention was during the celebration given to the last 10 years 1990–1999 when the Institute and its research programme passed significant changes. Summarizing them, it is possible to see that the intensity of research and its outcomes has remarkably increased.The scientific profile has developed towards the effective combination of theoretical research and its non-standard creative applications. The series of Activity Reports for particular years, accessible in the Institute library, illustrates this development.

During the last decade, the Institute has passed rapid changes in its organizational structure and partly even in the research orientation.

The budget limitations in early nineteenth lead to significant restrictions of the staffs in all academic institutes including ÚTIA. The end of the embargo regarding the import of advanced technologies has allowed to minimize the technical development of hardware which was not directly connected with the results of theoretical research.

On the other hand, the members of the Institute are quite successful in their grant applications. The grants mean an essential support of the research activities.

Since 1995 the Institute hostes a new service department for the technical service of campus Mazanka. In spite of it the rate between research and service (administration, computing centre, building and campus service) staff regulary develops in favour of the researchers.

The publicational activity of the Institute members displays a stabilized level regarding its quantitative as well as qualitative features.

The following tables and graphs illustrate some of the significant data about the development of the Institute during last ten years.

International Conferences in 1990–1999
Organized and Coorganized by the Institute

- 11th Prague Conference on Information Theory, Statistical Decision Functions and Random Processes. Prague 1990.

- Joint UK-Czechoslovak Seminar: Advanced Methods in Adaptive Control for Industrial Applications.

- International Symposium on Fuzzy Approach to Reasoning and Decision-Making. Bechyně 1990.

- Workshop on Uncertainty Processing in Expert Systems. Alšovice 1991.

- SIMONE User's Group Meeting, Prague 1991.

- Neural Nets and Systems Applications. Prague 1991.

- International Symposium on Simulation of Systems. Prague 1991.

- International Summer School: Computational Aspects of Model Choice.

- IFAC Workshop on Architecture and Algorithms for Real–Time Control, Prague 1991.

- Workshop on Nondifferential Problems in Optimal Design. Prague 1992.

- Workshop of SIMONE Users. Prague 1992.

- Joint Workshop on Discrete Event Systems. Prague 1992.

- IFAC Workshop on Mutual Impact of Computing Power and Control Theory. Prague 1992.

- 2nd IFAC Workshop on System Structure and Control. Prague 1992.

- Workshop on Progress in Transputer Technology. Prague 1993.

- Workshop on Innovative Approaches to Modelling and (Optimal) Control of Large Scape Pipeline Networks. Prague 1993.

- 3rd IFIP WG–7.6 Working Conference on Optimization-Based Computer-Aided Modelling and Design. Prague 1994.

- Workshop on Uncertainty Processing in Expert Systems. Třešť 1994.

- 12th Prague Conference on Information Theory, Statistical Decision Functions and Random Processes. Prague 1994.

- 1st IEEE Workshop CPM'94. Prague 1994.

- 17th IFIP Conference on System Modelling and Optimization. Prague 1995.

- Summer School on Adaptive Control. Prague 1995.

- Workshop on Industrial Control and Management Methods. Prague 1995.

- 2nd ERCIM Workshop on Systems and Control. Prague 1996.

- 2nd IEEE Workshop on Computer-Intensive Methods in Control and Signal Processing. Prague 1996.

- 3rd Conference on Distributions with Given Marginals and Moment Problems. Prague 1996.

- 7th World Congress of International Fuzzy Set Association. Prague 1997.

- Workshop on Statistical Techniques in Pattern Recognition. Prague 1997.

- Prague Stochastics'98. Prague 1998.

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

- Workshop on Conditional-Independent Structures and Graphical Models. Toronto 1999.

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Contents

1 Department of Decision–Making Theory

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J. Nosál	–	University of Economics
M. Sochorová	–	University of Economics
J. Cach	–	Charles University
P. Beremlijski	–	VŠB Ostrava

Grants and Projects:

- F. Matúš: Entropy functions and polymatroids.
  (Grant GA AV ČR No. A107 5801)

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

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.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)
    - Optimization methods. (J. Vomlel)

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

- Prof. Imre Csiszár (A. Rényi Inst. of Math., Budapest)

- Dr. Andreas Ruffing (University of Munich).

Most of the research activities of the department belong 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 Optimal Design of Topology and Material of Mechanical Structures

We continued studies of *Free Material Optimization* problems [8]. The goal is to find an optimum design of a material in a two- or three-dimensional continuum elastic body. The design variables are the *material properties* which may vary from point to point.

In the year 1999, we focused on problems with additional technological constraints on the stability of the optimal structure. Here the goal is to design a structure/material which can withstand a given load, is as light as possible and does not collapse due to global instability. To include the stability conditions, we have to work with a large-displacement nonlinear elastic model. We have shown that

the stability constraint can be formulated as a condition on positive definiteness of certain matrix [130]. The resulting optimization problem is a nonconvex semidefinite program. We have proposed several techniques of solving this, so far unsolved, problem [7].

We further continued in developing a software tool for free material optimization called MOPED (Material OPtimization in Engineering Design). We released the first official version of this tool which enables to solve problems of large dimension for general two-dimensional elastic bodies [131]. We have developed and implemented numerical and graphic tools for engineering interpretation of the numerical results [84].

1.2 Generalized Equilibrium Models

To encompass a large class of equilibria in one convenient model, we have introduced a new generalized equation, given by two single-valued and one set-valued map. In this way, one can model among others so-called variational inequalities of the 2nd kind and a class of hemivariational inequalities. For optimization problems with such equilibria as constraints we have derived necessary optimality conditions [206] on the basis of the generalized differential calculus of B. Mordukhowich. Conversely, this special optimization problem motivated a development of a nonsmooth 2nd-order calculus, where, in cooperation with B. Mordukhovich, we have obtained several new calculus rules. In this new framework we have considered also mathematical programs with some standard equilibria (nonlinear and mixed complementarity problems) from the numerical point of view. The proposed penalty methods are described in [208] and [207].

1.3 Conditional independences among four variables

In a series of three papers [181], the conditional independences within a system of four discrete random variables were studied simultaneously. The problem where independences can occur at the same time, called the problem of probabilistic representability, was attacked first by an analysis of cones of polymatroids. This approach led to the notion of semimatroid and its representations. New results on the cone of all polymatroids satisfying Ingleton inequalities enabled to reduce the problem to a class of non-Ingleton semimatroids.

Numerous new properties of stochastic conditional independence were found. Their proofs are based on fundamental properties of conditional independence and, in discrete case, on use of I–divergence, conditional information inequalities, and algebraic manipulations with marginal probabilities. Five examples, some of them quite sophisticated, of four-tuples of random variables were supplied to witness the probabilistic representability of non-Ingleton semimatroids. As a consequence, all combinations of conditional independences within four random variables which can occur simultaneously were described. This entails the true inference mechanism for conditional independence, namely, knowing that some conditional independences within a four-tuple of random variables (taking a finite number of values) hold, one can derive all conditional independences holding necessarily among the four variables. This kind of inference on the stochastic conditional independence is of great interest for multivariate statistics, and for applications in artificial intelligence.

1.4 Matroid Representations by Partitions

A matroid on the ground set N with the rank function r is said to be partition representable of degree $d \geq 2$ if partitions ξ_i, $i \in N$, of a finite set Ω of the cardinality $d^{r(N)}$, exist such that the meet-partition $\xi_I = \bigwedge_{i \in I} \xi_i$ has $d^{r(I)}$ blocks of the same cardinality for every $I \subseteq N$. Partition representable matroids are called also secret-sharing or almost affinely representable and partition representations correspond to ideal secret-sharing schemes or to almost affine codes. These notions have been reexamined in a recent paper by F. Matúš [182]. A new close relation to generalized quasigroup equations read out of the matroid structure was revealed: there is a one-to-one correspondence between solutions of the equations and the representations. A special morphism of partition representations, called partition isotopy, was introduced. For a few matroids, the partition isotopy classes of partition representations were completely classified and related to classical generalized quasigroup equations (generalized associative, distributive and medial laws). An infinite set of excluded minors for the partition representability was constructed.

1.5 Alternative approaches to conditional independence.

In [35] a new abstract approach to the study of conditional independence was introduced. The approach is based on the concept of *conditional product* which generalized the idea ofactorization of a distribution in probabilistic framework. An axiom system for conditional product was introduced in such a way that the derived concept of conditional independence obeys usual semi-graphoid properties. The existence of the operation of conditional product satisfying these ax-

ioms is proved for several frameworks of conditional independence (discrete probabilistic framework, general probabilistic framework, relational databases) and disproved for a couple of graphical frameworks (undirected graphs, directed graphs).

An alternative graphical approache to description of conditional independence structures was developed [212]. *Regular annotated graph* is an undirected graph whose edges are annotated by sets of vertices in such a way that three regularity axioms are safisfied. A specific membership algorithm allows one to test whether a certain conditional independence statement is represented in such a graph. Thus, every regular annotated graph induces an abstract conditional independence structure which was proved to satisfy graphoid properties. Moreover, an annotation algorithm allows one on basis of a nest of undirected graphs to construct a regular annotated graph which represents just the graphoid closure of the collection of all conditional independence statements induced by undirected graphs in the nest. In particular, every graphical model induced by an undirected graph, a directed acyclic graph or a chain graph can be described by an annotated graph as well.

In connection with the concept of complexity of a structural model of conditional independence structure, theoretical groundings of the idea of algorithmic implementation of a closure operation (for conditioanl independence statements) described by means of syntactic inference rules were written in [52].

1.6 Conditional independence in possibility theory

We have overviewed a great deal of conditioning rules and conditional independence relations that have been in-

troduced in possibility theory and compared their properties. Special attention was paid to the measure-theoretical approach to conditioning and independence presented parametrized by continuous t-norms. This way of conditioning produces almost all of previously introduced conditioning rules. Similarly, adopting conditional independence notion, we will obtain most of previous definitions of conditional independence relations. Especially, this approach unifies the best-known notions of Zadeh's conditional noninteractivity and Hisdal's conditional independence and other independences for particular t-norms. Therefore, this approach is both unification of most of formaly proposed conditioning rules and conditional independence notions and their generalization.

Properties of this measure-theoretical approach to conditioning and conditional independence correspond to those possessed by stochastic conditional independence, i.e. for *any* continuous t-norm conditional independence defined in this way satisfies *semi-graphoid properties* and for *no* continuous t-norm it satisfies *graphoid property* for general distribution. We also proved, that for a wide class of *Archimedean* t-norms strict positivity of possibilistic distribution implies graphoid property [263].

1.7 Envelopes of a simplex of discrete probabilities.

One of the standard problems in decision making theory with probabilistic background is to define a *joint distribution* that fulfills certain conditions. These conditions are claimed to contain certain knowledge about the real world. They may be given in a form of less-dimensional distributions (the so called *oligodistributions*) that are considered as true theoretical *marginals* of the looked-for theoretical distribution.

This formulation is referred to as *marginal problem.*

In general, if the conditions, as a whole, (i.e. the set of oligodistributions) obey some other conditions (e.g. *strong consistency*), there exists a whole set of joint distributions whose marginals are equal to the fixed oligodistributions. In such a case, it is possible to choose certain strategy for selecting only one appropriate representative of the set of *feasible joint distributions.* Then, this resulting joint distribution is referred to as an *extension* of the oligodistributions. E.g if *relative Shannon entropy* is used as the selection strategy, the result is called the *maximal entropy extension* (of the oligodistributions). There exist dozens of different approaches.

If we wish to solve certain analogy of marginal problem for case of *inconsistent oligodistributions,* it is necessary to modify the input oligodistributions, preferably, in the least possible way to get some solutions. In this case, the unicity is the direct consequence of the requirement for minimal changes. If the knowledge is given in form of *conditional probabilities* and certain *graphical form* representing the *conditional independence* between *random variables* is provided, the resulting model is called *Bayes network.*

If sets of conditional probabilities are considered as primal concept, the *coherence problem* is solved in the context of de Finetti's *subjective probability.* When both oligodistributions and conditionals are fixed, we solve *conditional problem.* See [160].

Returning back to the original *marginal problem,* we may look not for a single representative (an "average" extension), but we may be interested in "boundary" points of sets of distributions. Generally, the boundary is created as a collection of less-dimensional simplexes representing the "edges" of the

simplex of all relevant joints. However, not everything has an interesting interpretation. On the other hand, we may try to find the distributions with the largest and with the smallest "discernment power". This may be done in different ways. E.g. *lower* and *upper Bayesian extensions* are suggested that constitute the *envelopes* of a set of joint distributions with fixed input oligodistributions.

It is possible to think about an even broader concept of *envelopes* where, for each *atomic event*, a pair of *joint distributions* is given. This couple of distributions defines an interval for *aposteriori probabilities* given by all *feasible joints* for the *event*.

2   Department of Control Theory

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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.

M. Šebek is the coordinator of EUROPOLY - The European Network of Excellence for Industrial Applications of Polynomial Methods. This large project is supported by European Commission. It is participated by thirteen European groups leading in the field of polynomial methods, namely ÚTIA Prague, CZ; University of Twente, NL; University of Strathclyde, UK; University of Glasgow, UK; Politecnico di Milano, I; LAAS CNRS, F; University of Uppsalla, S; Compureg Pilsen, CZ; Faculty of Technology Zlín, CZ; Slovak University of Technology, SK; ProCS Šala, SK; Czech Technical University, CZ; and University of Warsaw, P. The current list of EUROPOLY external members include Daimler-Chrysler, D; Duslo Šala, SK; Easy Control, CZ; Ericsson, S; PolyX, Ltd., CZ; ETH Zürich, CH; Johannes Kepler Universität Linz, A; and UMIST, UK. Interested European industries and research groups are welcome to join the Network. For info on numerous EUROPOLY activities, visit its Web site at `www.utia.cas.cz/europoly/` .

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).

Grants and Projects

- S. Čelikovský, Nonlinear Systems: New Approaches to Control and Detection (Grant Agency of the Academy of Sciences of the Czech Republic)
- S. Čelikovský, M. Šebek: Numerical algorithms for control and filtering (Grant Agency of the Czech Republic).
- S. Čelikovský, Control and Observation of nonlinear Systems (Czech–French project Barrande)
- J. Doležal, Prague Technology Center (Honeywell)
- V. Kučera, Robust Control Systems Design (Grant Agency of the Czech Republic)
- V. Kučera, Robustesse et structure des systemes lineaires sur anneaux (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)
- M. Šebek, Industrial Applications of Polynomial Methods (Czech–Japanesse project)
- M. Šebek, Systems with Uncertainty and Constraints (Czech-French project – Barrande)
- M. Šebek, EUROPOLY – The European Network of Excellence for Industrial Applications of Polynomial Methods (European Community – Copernicus)
- M. Šebek, Analysis of Multidimensional Systems with Applications to Synthesis and Control (Czech–Italian project).

Teaching Activities

- S. Čelikovský, Modern Nonlinear Control, and Advanced Topics in Nonlinear Control, CINVESTAV unidad Guadalajara.
- V. Kučera, Faculty of Electrical Engineering, Czech Technical University, Prague: Algebraic Approach to Control System Design (graduate), Linear Systems (graduate).
- M. Šebek, Faculty of Electrical Engineering, Czech Technical University, Prague: Robust Control (graduate) and Algebraic Design Methods (postgraduate).
- V. Kučera is a member of the Accreditation Board appointed by the Government and a member of the Scientific Boards of two universities (Czech Technical University, Prague and University of Western Bohemia, Pilsen) and three faculties (Faculty of Electrical Engineering and Faculty of Mechanical Engineering, Prague and Faculty of Mechatronics, Liberec).
- V. Kučera is Chairman of the national jury for Doctor of Science research degrees in Engineering Cybernetics and Computer Engineering.

Invited Lectures

V. Kučera: H_2 control theory: a blend of classical and modern techniques, AMETMAS-NOE Workshop, St. Petersburg.

V. Kučera: Jak kvadratickým kritériem jednotlivé póly přemístit, Process Control Conference, Tatranske Matliare.

V. Kučera: Control theory: a dynamic field, IFAC World Congress, Peking.

V. Hromčík: Polynomial Toolbox 2.0 ICIMS NOE Technology Transfer Workshop, Praha, ÚTIA AV Č).

V. Hromčík: Polynomial Toolbox 2.0 and Simulink, 1st EUROPOLY Workshop, University of Strathclyde, Glasgow.

V. Hromčík: Využití Polynomiálního toolboxu při výuce algebraických metod návrhu řídicích systémou, Setkanie kateder a ústavov automatizácie PÍLA'99.

J. Ježek: A numerical algorithm for spectral factorization by means of interpolation, AMETMAS-NOE Workshop, St. Petersburg.

J. Ježek: Matrix polynomial approach to control of technological processes, AMETMAS-NOE Workshop, Leuven.

Our Visitors

- A. Bricaire, CINVESTAV del IPN, MEX
- P. Colaneri, Politecnico di Milano, I
- M. Fikar, Slovak University of Technology, SK
- K. Galkowki, Technical Univeristy of Zielona Góra, PL
- M. Grimble, Univeristy of Strathclyde, GB
- H. Golee, University of Glasgow, GB
- W. Haas, University of Linz, Austria
- D. Henrion, LAAS-CNRS Toulouse, FR
- Vincent van Hessch, LAN de Nantes, FR
- H. Kwakernaak, University of Twente, Enschede, NL
- J. Lunze, Technische Universität Hamburg, D
- A. Marquez, IRCYN, Nantes, FR

- C. Moog, IRCYN, Nantes, FR
- R. Pothin, IRCyn, Nantes, FR
- S. Vasileva, BG AS, BG
- K. Zehetleitner, Univeristy of Linz, Austria

Representation in International Societies

J. Doležal – President of the Czech Committee for IFIP and Full Member Representative in IFIP General Assembly;

V. Kučera – President Elect of IFAC 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.

Editorial Boards

J. Ježek – Kybernetika;

V. Kučera – Bulletin of the Polish Academy of Sciences;

       – International Journal of Control;

- International Journal of Robust and Nonlinear Control;
- International Journal of Systems Science;
- Kybernetika.

M. Šebek – European Journal of Control;
- IEEE CSS Conference Editorial Board.

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 including chaotic systems;
- analysis and design of nonlinear control systems.

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

2.1 Pole Placement via Quadratic Optimization

Very often, quadratic optimization is used to stabilize a linear system or to improve its dynamics. In such a case, a quadratic cost function is constructed so as to achieve desired pole positions for the closed-loop system. However, the relationship between the weighting matrix, which specifies the cost function, and the resulting closed-loop pole positions is very complicated.

A simple and elegant solution has been found in the case of state feedback control systems [140], [150]. In particular, a weighting matrix has been identified which shifts one selected pole, or a pair of complex conjugated poles, to a specified position while leaving the remaining poles at place. The new position, however, is not arbitrary as long as the weighting matrix is to be non-negative definite.

The relationship is very simple in this case and can be used in a systematic manner to improve the control system dynamics. The designer just displays the poles, selects one which is to be shifted, allocates it to a desired (and allowed) position via a simple quadratic optimization, and repeats the procedure until all poles are placed in the positions desired. The quadratic optimization problem involved in shifting a single pole results in a rank-one matrix Riccati equation (rank-two to shift a complex conjugate pair) and admits an explicit solution.

2.2 Numerical Algorithms for Polynomial Matrices

A new class of computational procedures - called the second generation - has been developed that is based on interpolation and Sylvester matrices. It currently includes solvers for various special polynomial matrix equations and first numerically stable procedures for triangularization, greatest divisors and rank evaluation of polynomial matrices The second generation methods appear to be more efficient as well as more reliable than classical routines [69, 70, 71].

Quite recently, a break-through has been achieved leading to brand new group of methods - tentatively called the third generation - that is even more reliable and namely more efficient than the second generation. These methods employ sophisticated interpolation using discrete Fourier

transform and enable to use Fast Fourier Transform (FFT) procedure. The first algorithms derived include determinant, rank and adjoint computation for a polynomial matrix and their performance is really extraordinary [86, 87].

2.3 Stabilizability and Stabilization of Nonlinear Systems

New approaches to stabilization of various nonlinear systems have been derived that conquer the well-known drawbacks of traditional methods based on linearization. Nonlinear systems without well-defined (that is controllable and observable) approximate linearization cannot be stabilized by classical techniques. Thanks to sophisticated analysis of their structure with singularities, new methods have been developed for their stabilization as well as for asymptotic tracking and disturbance rejection [32].

2.4 LMI for Polynomial Methods

Linear Matrix Inequalities (LMIs) are now widely used as a convenient tool for solving a significant number of control problems. Probably for historical reasons, LMIs have mainly been used conjointly with state-space methods. Several our recent works however tend to prove that polynomial (or algebraic) methods can also rely on LMIs. It is now evident that the simultaneous use of LMIs and polynomial methods can shed new insights into several important control problems such as simultaneous stabilization, robust stability testing for a polytope of polynomial matrices, D-stability testing, etc [73, 74].

3 Department of Adaptive Systems

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Year 1999 has been full of changes within the Department staff. It was "harvesting" year for PhD thesis. Ing. H. Gao,

PhD, Ing. T.V. Guy [58], Ing. F. Kraffer, PhD and Ing. J. Rojíček, PhD defended their thesis. Mgr. L. Jirsa [103], Ing. L. Tesař [249] and Ing. P. Ivanova have submitted them. N. Khailova and M. Valečková will submit them (hopefully) soon. Thus it is not surprizing that a new generation of PhD students joined us (K. Belda, Li He, P. Gebouský and V. Šmídl). Some students (M. Králík, A. Regner and S. Pěnička) found that there are other interesting things in life than science and left us. We wish them all good luck in life. Creation of Signal Processing Department formed by our former members working with Dr. J. Kadlec is the major change encountered. We wish them success.

Activities of the Institute include cybernetics and informatics as the fields dealing with analysis and design of systems generating predictions, making decisions or controlling other systems. Our Department inspects systems that have the 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 we have reached significant conceptual, theoretical, algorithmic, software and application results. This history is reflected in special issue of the journal Adaptive Control and Signal Processing devoted to Václav Peterka, founder of our Department [114]. Also, his seminal work on self-tuners was reprinted. Gradually, the Bayes-based theory of decision making under uncertainty [118, 199] 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.

- We learn what complexity means by solving demanding

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problems in radiation protection, in transportation, in technological systems, in nuclear medicine etc.

- We gradually improve our know-how in order to widen the applicability of "classic" adaptive systems to complex cases.
- We inspect theoretically possible new approaches to the construction of adaptive systems.

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

Grants and Projects

ity and adaptivity of uncertain systems (GA AV ČR A2147701, successfully finished)

- M. Kárný – *Fault Detection and Isolation - Cooperation with Slovenia* (MŠMT ČR ME 245/1998)
- F. Kraffer – *Algebro-geometric methods for polynomial matrix operations with applications in control system design* (GA ČR 102/99/D033)
- P. Nedoma – *Enhancement of the EU decision support system Rodos and its customisation for use in Eastern Europe* (Copernicus PL963365, [Rodos], successfully finished)
- P. Nedoma – *Adaptive systems: theory, algorithms and software for practise* (GA ČR 102/97/0118, successfully finished)

University Courses

Education is an integral part of the research. This is reflected in the fact that we are supervising a relatively high number of MSc theses and undergraduate research projects. To attract the interest of students, the members of the Department give regular (under)graduate courses:

- Faculty of Physical and Nuclear Engineering, Czech Technical University (ČVUT)
  Adaptive Control (M. Kárný)
- Faculty of Transportation, ČVUT
  Course of Probability Theory and Statistics (I. Nagy)
- Faculty of Electrical Engineering, ČVUT
  Predictive Control (J. Böhm)
  CAD of Control Systems (P. Nedoma)

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.

International Cooperation and Travels

A substantial energy has been spent on preparation of an international PhD workshop *Cybernetics and Informatics Eurodays: Young Generation Viewpoint* to be held in September 2000. It is organized (by and) for students, young researchers and engineers working in the field of Cybernetics and Informatics. This interdisciplinary workshop should help young people to build new contacts in the field of science, present their research results and inform them on the progress of their colleagues.

Conference trips were mostly connected with successful presentations. The key actions were:

- L. Bakule
long-term stay at UPC, Barcelona, Spain,
5th ILAS Conference, Barcelona, Spain (invited lecture),
9th IFAC/IFIP/IMACS/IFORS Symposium on Large Scale Systems, IPC member,
Member IFAC TC Large Scale Systems
- J. Böhm
lecture in CSCC'99, Athens
lecture in Process Control'99, Tatr. Matliare
- J. Bůcha
lecture Process Control'99, Tatranske Matliare
study visit, participation on IJCAI'99, Stockholm [23]
- H. Gao
lecture, American Control Conference, San Diego, USA
research visit, Mondragon University, Spain
- T.V. Guy
lecture, European Control Conference, Karlsruhe, GER

study visit, Josef Stefan Institute, Ljubljana, SLO
- M. Kárný
  preparation of IST project Prodactool, Vien, Austria
  preparation of IST project Prodactool, Reading, UK
- F. Kraffer
  lecture, 7th IEEE Med, Haifa, Israel,
  invited lecture, Dept. Appl. Math., E.T.S.I.T., UPV, Spain
- R. Kulhavý
  lecture, IFAC World Congress, Beijing, China
- P. Nedoma, P. Pecha
  Rodos coordination meeting, Rhodes, Greece
- L. Tesař
  lecture, European Control Conference, Karlsruhe, GER

RESULTS

3.1 Clustering Improving Operator's Performance

Sensors installed on complex processes (rolling mill, transportation system, computer supported medical diagnostic system etc.) offer to the operator a lot of data which should be used for an efficient maintenance of the process in question. The resulting performance depends heavily on the skills and mood of the operator. Thus it is desirable to provide an advisory system that drives him to high performance areas and warns him against probable system misbehaviour. An original theoretical and algorithmic basis of such advisory system was elaborated within 1st Phase Esprit project ProDacTool and formed firm basis of the full scale EU Project IST-1999-12058. It is based on the following idea: the differences in operation quality are believed to manifest themselves in different modes of the distribu-

tion of the observed data. This distribution is approximated by a mixture of unimodal distributions (components). Each component is qualified by the expected performance and the best one provides a basis for the advisory system: the operator is shown apropriate univariate cross-sections on it. The efficiency of this approach has been demonstrated on simulated and real rolling mill data. Its success stems from our ability to efficiently perform mixture estimation in high dimensional spaces (say 50 000 records each containing 40 variables). It was achieved by a novel combination of an efficient Mean-Tracking algorithm with quasi-Bayesian estimation of mixtures. The latter algorithm has been recently extended to mixed continuous and discrete variables and applied to fault detection and isolation [118, 196].

3.2 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. Their efficient implementation is, however, nontrivial.

The ambitious project of their computer-aided design launched several years ago has been succesfully finished for single-input single-output systems. The MATLAB toolbox ABET99 [198] is now available for complete "batch" design of adaptive controllers. The toolbox functions converts system measurements, user's knowledge, objectives and restrictions into a completely pre-tuned controller. The design result is a C-encoded function that is implemented in real-time control.

The ideas of the toolbox object-oriented design have been

summarized in [199]. It offers a methodology and software tools for design of complex decision making toolboxes.

A project of an *interactive* design of adaptive controllers, DESIGNER 2000, continued and was finished. It dealt mainly with design of graphical user interface and the elicitation and utilization of knowledge in controller design [25].

The present 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. Experience with the relevant algorithm for the conversion is described in [120, 121]. The algorithm weights the processed knowledge items so that a suitable compromise is found in spite of their imprecise, repetitive and contradictory nature. This:

- 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.

Refinement of sequential stopping rule. A substantial part of evaluations performed in the discussed area relies on simulations. They should provide reliable estimates of inspected quantities. Thus they should rely on long runs. The simulation length decides on computational time which can easily become excessive. Thus a compromise is needed. This stimulated development of a sequential stopping rule that balances the gained precision and computational load. This rule was proposed formerly within a classical theory of sequential stopping on a universal model relying on ergodicity of the inspected process. This rule was implemented into

ABET99 system and successfully experimentally verified for efficiency and reliability.

Advances in the control design. General algorithm for LQ synthesis, which is based on input-output models has been extended for MIMO systems. The technique of tuning the controller [19], available for SISO systems is gradually transfered to the MIMO version. Basic blocks of Matlab and Simulink MIMO Toolbox were created.

Spline-based adaptive LQ hybrid controllers provide complement to the discrete-time controllers. The main idea of the proposed controller is to combine the convolution modelling of continuous controlled system and piecewise approximation of signals. The approach uses a spline approximation of signals and continuous time quadratic loss function. Thus, the gained controller respects 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 [60, 58, 59].

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 data-dependent penalizations. Extensive tests performed with this toolbox and documented in [18] help the user:

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

Functionality and reliability of DESIGNER 2000 has been tested systematically. The majority of tests aimed to

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detect the role and influence of prior information on control design quality [123].

Object oriented design. New methods of object oriented design have begun to be used in the DESIGNER 2000 project. They are based on Unified Modeling Language. It supports the seamless integration of algorithmic, graphical user interface and knowledge oriented DESIGNER 2000 parts.

3.3   Modelling and identification of traffic systems

The problem of heavy car-traffic in large cities become pressing almost all over the world. We have addressed several tasks contributing to the counteracting this situation.

Generally, we deal with in modeling, identification and control of traffic micro-regions which can be composed together creating large traffic networks on the basis of Bayesian statistics [117]. As control actions, we consider use of the periods of signal lights in the crossroads of the region. The measured data reflect intensities and densities of traffic flow. Detectors placed under the surface of the roads near crossroads provide them.

Specifically, we consider the following tasks:

Simulation of traffic region. Micro-modeling approach (i.e. modeling of each particular car) is used. The purpose of the simulation is twofold: to be a source of data which are simulated but close to the reality or to visualize a situation of traffic region just identified.

Data filtration and traffic prediction. The existing measuring devices are often unreliable and improperly placed. Thus data filtration and elimination of superfluous data are necessary. Piece-wise modelling of signals studied in connection with hybrid controllers [58] provides the basic filtering tool. It

also serves for prediction of traffic using almost static model and offset modelling periodicities during the week. Data reduction is based on weighted variants of principal component analysis we learnt in connection with image processing in nuclear medicine [231].

Identification of directional relations. Knowledge of proportions in which cars are divided in average in crossroads is a necessary mean for constructing models of traffic areas from single crossroads or traffic networks from single areas. The directional relations are described by static multivariate regression model for which the algorithms of Bayesian identification [198] can directly be used.

Traffic state estimation. For complete description of the state of traffic, intensity and density of traffic flow are necessary. They are represented by points in the state plain. The typical states of traffic can be recognized as clusters in the plane. For modeling the mixture model with components corresponding to particular clusters is used. Identification not only searches for the proper positions of clusters but gives also current prediction of the active cluster. It performs classification [196]. The idea can be extended from the plain to high-dimensional space with many measured variables [118].

3.4   Robust Control of Multivariable Systems

A large class of engineering problems admits the simplest model – a finite-dimensional linear time-invariant system – where state space and frequency domain are the two main design methodologies. In control applications with vector-valued signals, classical polynomial methods of frequency domain generalize to multivariable methods based on polynomial matrices. The polynomial matrix methods, however,

lag behind their state space counterparts in several aspects.

Principal reasons for the restricted applicability of polynomial matrix methods are numerical unreliability and inability to compute system-theoretically relevant solutions to various polynomial matrix operations like linear and quadratic equations. Publications [138] and [139] describe applications of geometric-type techniques in the computation of polynomial matrix operations. Advantages over existing methods are avoidance of elementary polynomial operations in computation, application of ideas found in numerical analysis literature, and level of abstraction just high enough – although higher than in the mainstream literature – to separate structural questions from computation.

3.5 Decentralized Control of Large-Scale Systems

A new extension of the Inclusion Principle has been achieved for quadratic control of linear time–varying dynamic systems. The results are based on a general structure characterization of complementary matrices involved in the input-state-output Inclusion Principle by [5], which enables the formulation of explicit conditions on the complementary matrices that are significantly easier than the conditions considered up to now. Moreover, these conditions offer much more flexible choice of complementary matrices both for analysis and synthesis of control problems. This extension of the Inclusion Principle has been adopted on the LQ control design by using overlapping decompositions in [4]. It includes an original generalization of pairs composed of system and criterion. New results concern quadratic optimal control of both general LTV systems and commutative class of LTV systems. Particularly, only implicit conditions have

been derived for general LTV systems because the transition matrix in expansion containes complementary matrix implicitely. To derive explicit conditions, the specialization on a commutative class of LTV systems has been used. It has been shown that the extension of quadratic optimal control from LTI to LTV commutative systems is possible. Moreover, the advantage of this new approach has been demonstrated when comparing it with standard contraction-expansion procedures for optimal control by using aggregations and restrictions. Further, new existence conditions have been proved for expansion-contraction forms ensuring simultaneuos controllability-observability of both subsystems overall systems in expansion.

The results on H_∞ decentralized control design by using the Riccati equation approach by [3] have been tested on simulation the control design of a building structure under earthquake excitation. Variouos decomposition strategies have been considered, mainly in the context of matching conditions and locations of actuators. Selected results have been presened in [1].

3.6 Memory-Based Models in Control & Optimisation

The recent progress in database and computer technology makes it possible to use for control and optimisation of technological processes the whole process history. Being more flexible and faster than a global model and more precise and robust than a local (recent-data) model, memory-based approach offers an attractive alternative to the current paradigms. The paper [157] outlines the traditional view of local regression, shows its Bayesian extension and discusses practical choices affecting data retrieval and smooth-

ing. Memory-based methods are especially appropriate for autonomous systems functioning in environments that are not known in advance or which are changing and in which the designers will not be able to tune the system parameters during operation. We approach the problem of system identification through the memory-based learning paradigm. If there is a continuous stream of new training data intermixed with queries, as is the situation ind ynamical system identification, it is less expensive to train and query a memory-based method than it is to train and query a global non-linear parametric model. We shown that the memory-based method is a viable approach to fault detection and diagnosis. Preliminary studies prove it as more reliable for pattern recognition than some of the traditional methods. Some aspects of practical implementations (dealing with locally inadequate amounts of training data, methods for assessing the quality of the estimation, filtering of noise, identify ingoutliers, automatic tuning of parameters) are considered. Finally, we explore an approach to dealing with practical fault detection scenarios when the available database is huge.

3.7 Fault Detection and Isolation

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 was summarised in [116]. MATLAB toolbox developed in connection with aformer COPERNICUS project and in co-operation with Slovenia is described in [248]. It contains mainly mult-

model based techniques that can be compared with built in classical methods. Multi-model techniques rely heavily on efficient numerical solutions. Bootstrap techniques are adapted and extended in [249, 115].

3.8 Information Geometry of Nonlinear Estimation

The lack of an analytical solution to Bayesian identification of non-linear or non-Gaussian models gave birth to a multitude of approximation algorithms. It is quite difficult for the user to compare the existing options and make an appropriate choice. Additional insight can be gained from the fact that estimation itself is an approximation problem, namely that the posteriordensity is closely related to the information divergence between the empirical and model distributions of observed data. The empirical distribution, the family of model distributions and the information divergence between the empirical and model distributions represent three major ingredients of the estimation problem. Any approximation of the Bayesian paradigm necessarily affects at least one of these objects. Following this pattern, in [159] we present three approximation paradigms: based on local weighting of observed data, reduction of the model family and direct approximation of the information divergence.

3.9 Integration of all Cognitive Functions

Utilization of knowledge plays an important role in systems developed in our Department. We need to aid and extend our algorithmic solutions by knowledge-based approaches and, in the outlook especially, by the support of knowledge

acquisition. The corresponding areas of knowledge representation and utilization are well developed, and knowledge creation is well developed for applications covering relatively simple systems. Due to our orientation on real applications the extension of knowledge creation, i.e. (machine) learning to the areas of complex systems is very suitable.

We have continued to address this problem. We consider learning to be one of (basic) cognitive functions. The envisaged approach stems from observation that all cognitive functions are very intertwined. For example, learning cognitive function is interconnected with practically all other cognitive functions, like identification, (decision) implementation, (attention and reliability) control etc., and vice versa, learning participates in all remaining cognitive functions. This is why the learning problem is solved in a broader context, in a context of problem solver (PS). PS is being designed to integrate all cognitive functions into a single system.

Another important characteristic of the approach is the self-reflection of PS. This is applied not only to PS, but also to the whole approach. Again, it stems from realization that the results of learning research, i.e. that, what have been discovered about learning processes can be used for the design of PS. This has led, for example, to the attempt to collect "all" available knowledge, gained in the areas of artificial intelligence, machine learning, computer science, control engineering etc., and to apply it to the design of learning and PS itself.

This is a very complex task and it is, by the way, impossible to describe it precisely, in limited space, here. In the range of "all available knowledge", it is also necessary to use knowledge how to cope with complexity. Also, for ex-

ample, the solution relies on knowledge from object-oriented technology, computer aided software engineering approaches and tools, Unified Modeling Language, uncertainty and inconsistency processing etc. [21, 22].

3.10 Customisation of the RODOS system for ČR

EU software product RODOS (Real time Online DecisiOn Suport)has been customised such a comprehensive decision support tool for nuclear emergency management. Localisation of the product for conditions of the Czech Republic consists of adaptation of various models, local data collection, their pre-processing and importing into RODOS database as well as quality assurance of the system.

Profound analysis of the RODOS food-chain module from the point of view of its use for the Czech territory was done [215] including the new definition of radioecological regions for the whole country. The results were also delivered into the joint EU report [214] dealing with the review of the adequacy of RODOS food-chain and dose calculations for European scale. Collection of required data for each radioecological region of CR and their reprocessing and integration into RODOS are described and sent for merging with European data for other regions.

Quality assurance of the product was extended to the customisation tasks including QA of local data [215]. Stepwise improvements of complex model parameters on the basis of co-operation with external expert teams has been accomplished. Data preprocessing subsystem has been developed for purposes of missing gridded data reconstruction. Compliance of the RODOS design with the governmental

regulations fixed in the new Czech Atomic law has been checked.

In connection with the RODOS project, methodology and software tools for partial evaluation of radiological impact on population initiated by both accidental and routine atmospheric radioactive releases have been thoroughly examined. Results of comparison analysis between various codes are reviewed in [217].

3.11 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. Its use has contributed to reliable estimation of various quantities met in nuclear medicine, mostly describing the dynamics of accumulation/elimination of ^{131}I. The research has reached advanced stage so that the resulting data processing [77, 103, 104], is now practically tested in connection with the treatment of thyroid gland diseases [105], [76]. Non-traditional ways of accumulation/elimination modelling [78], [79] brought a novel view on some formerly observed discrepancies between diagnostic and therapy evaluations [80]. They are being implemented in system JOD*NEW* [282], [281].

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Grants and Projects

- J. Kadlec (J. Schier) – *High Speed Logarithmic Unit* (ESPRIT 33544 LTR Phase 2, 1999-2001)
- J. Kadlec (M. Kadlecová) – *"IDEALIST-EAST" Information Dissemination and European Awareness Launch for the IT Programme in East Europe* (Copernicus CP97-7122 1998-2000)
- J. Kadlec (I. Kadlecová, Central library of the Academy) – *Development of the infrastructure for research and development* (LB98250, INFRA II, 1998-2000)
- J. Schier – Research projects IMEC/Universities, period 1996-2001, project "Spatial Division Multiple Access Systems for Mobile Communications"
- J. Schier – OK 314 A High Speed Logarithmic Arithmetic Unit (The Ministry of education of the Czech Republic,1998 - 2000)
- J. Kadlec – OK 317 Decision-Support Tool for Complex Industrial Processes based on Probabilistic Data Clustering (The Ministry of education of the Czech Republic,1998 - 2000).
- J. Kadlec – OK 346 Information Dissemination and European Awareness Launch for the IT Programme in East Europe IDEALIST-EAST (The Ministry of education of the Czech Republic, 1998 - 2000).
- J. Kadlec – *Expert for the key action "Systems and services for the citizen"* (The Ministry of education of the Czech Republic, 1999-2004)

University Courses

The members of the DSP group give these selective courses:
- Faculty of Electronic Engineering, Czech Technical University
Adaptive methods for signal processing (J. Kadlec)
Parallel algorithms and architectures (J. Schier, J. Kadlec)

- Faculty of Transportation, Czech Technical University
Principles and Applications of Parallel Computation
(J. Kadlec)
Software Tools for DSP Programming (J. Kadlec)

Conferences

We have organized or co-organised several conferences related to EU projects in the area of IST:

- National conference to opening 5-th Fp., 5.2.99, Prague. There were 650 participants. Key speakers: Dr. Krenek, Dr. Chvojka from The Ministry of Education, Dr. Klusacek, director FEMIRC CZ and Dr. Barbara Rhode from EU 1[83].
- IST Information Day to 1-st IST Call. 2.3.99, Prague. There were 150 participants. Key speakers: Dr. Ulrich Boes, EU, Dr. G. Grunberg, EU IT Prize, Ing. Hillerova (NCP IST CZ), Dr. Klusacek (director FEMIRC CZ), J. Kadlec (NCP ID-EA CZ). Topics of the presentations were converted to WWW presentations, published at the ID-EA CZ server and advertised via e-mail lists.
- Seminar about 5-th Fp. 18.1.99, Prague, 20 participants. Speaker J. Kadlec, for researchers mainly from the UTIA institute of the Academy of Sciences.
- Seminar about 5-th Fp. 25.1.99, Prague, 10 participants. Speaker J. Kadlec, for mathematics mainly from the UTIA institute of the Academy of Sciences.
- Seminar about proposal writing. 30.3.99, Prague, 12 participants. Speaker J. Kadlec, for Faculty of Transport of the Czech Technical University.
- Seminar about proposal writing. 31.3.99, Prague, 7 participants. Speaker J. Kadlec, for companies: JanigaLabs, OR-CZ, SoftModel.

- Seminar about proposal writing. 7.5.99, Prague, 16 participants. Speaker J. Kadlec, for Institute of Computer Science of the Academy of Sciences.
- Presentation of ID-EA at the Press conference organised by the Press Department of the Academy of Sciences of the Czech Republic. 14.1.99, Prague.
- IST Information Day to 2nd IST Call. 23.9.99, Prague. There were 60 participants. Key speakers: Ing. Hillerova (NCP IST CZ), Dr. Klusacek (director FEMIRC CZ), J. Kadlec (NCP ID-EA CZ) [82].
  11. IST Information Day to 2nd IST Call. 29.9.99, Brno. There were 40 participants. Key speakers: Ing. Hillerova (NCP IST CZ) and J. Kadlec (NCP ID-EA CZ).
- Seminar about 5-th Fp. and Proposal writing, 17.9.99, Prague, 7 participants. Speaker J. Kadlec, for researchers from the Mathematical institute of the Academy of Sciences.
- Seminar about 5-th Fp. and IST 23.10.99, Prague, 20 participants. Speaker J. Kadlec, Dr. Hulova, for SME's directors.
- Seminar about 5-th Fp. and Proposal writing, 26.11.99, Prague, 6 participants. Speaker J. Kadlec, for the Czech Railways and Transport directors.

Guests

- *Dr. N. Coleman* (UK), 2 visits in connection with Esprit project 33544 22.3-26.3.99 and 2.8-6.8.99.
- *Christian Vialatte and Emmanuelle Legrand* (UK) visited us in connection with Idealist-east project, helping with www pages and the core of partner-search database (this covers their stage in Prague whike waiting for the workpermit). 2.99-4.99.

- *Barbier A., de Castellane L., Gautier L.-P., Gourguechon S., Leroy S., Paturle A.* (FR), Students from I.S.E.P. Paris, France at summer 3 week working visit. Focuss on I/O libraries for the rapid prototyping tools for tranputers.
- *J. Ondracka, R. Oravec.* (SK), Students from FEL STUB Bratislava, Slovakia. Two 2-day working visits, noise cancellation projects.

Travels and International Cooperation

In 1999 was our travel related mainly to coordination and working visits related to EU projects:
- J. Kadlec

Field programmable logic conference FPL99 Glasgow, UK 24.8-3.9.99.

Coordination of Esprit project, University of Newcastle, UK.

Coordination of Inco project Ideal-List-East and representation of Czech Republic with the CZ stand at IST99 exhibition, Helsinki, Finland.

Presentation of the company Software602 at a preliminary consortium meeting in Paris, 22.2.99.

IST Programme Information Day, Paris, 22.2.99. (Presentation of 23 CZ partners).

Presentation of company UNIS at the Workshop Digital Signal processing and Wireless Communications in Leuven, Belgium, 28.5.1999.

Presentation of ID-EA at ISEP in Paris and at the Dolphin, Ltd. in Grenoble, France 8.5-13.5.99.

8 participations as the CZ delegate at the IST committee of the EU IST programme. Brussels, Belgium.
- R. Matulík

Presentation of the note-taker for the blind at Czech Republic stand at the CEEC exhibition, IST99 Helsinki, Finland.

- J. Schier
Workshop Digital Signal processing and Wireless Communications in Leuven, Belgium, 28.5.1999.
- Ch. Vialatte
Coordination of Esprit project, University of Newcastle, UK.
Stay at Bulgaria Academy of Sciences, 23.8-3.9.
- R. Matoušek
Field programmable logic conference FPL99 Glasgow, UK 24.8-3.9.99.
DSP99 Germany, Munchen, 15.10-17.10.99.

The group has supported five management meeting trips needed for the negotiations of the 2-nd phase of the Productool project (M. Karný) and 2 similar supporting trips (E. Legrand) related to the partner-search activities.

RESULTS

3.12   Key Directions of the Group

Theory of identification, algorithmic design and mapping on parallel systolic arrays.
Applications in general area of digital signal processing, prediction, noise cancellation, and adaptive equalisation.
Implementations based on rapid prototyping techniques for embedded systems, signal processors and field programmable gate arrays.

Applications and implementations are the key factor for our work-motivation and help us to select the appropriate theoretical research themes, needed for successful solution of challenges of our research and development projects.

Our research is focussed on new fast systolic estimators with increased numerical stability with respect to insufficiently informative data. Bayesian probabilistic approach is

used as a tool for analysis of normalised identification algorithms for fixed-point signal processors [108].

Combination of the recent results in the area of Lattice filters with our links to the Bayesian research leads to new fast systolic algorithms for DSP applications equipped with determination of system structure or on-line testing of hypotheses.

We invest considerable part of our efforts to the research of modern design techniques for automated programming of parallel algorithms known as rapid prototyping. We can use the computing power provided by embedded multi-processor architectures. This allows us to keep open path to implementation of these research results and to participate on advanced EU-funded research projects [248],[106].

We develop tools for rapid prototyping leading to automated conversion of code from the simulation level to the code for embedded signal processors working in real-time [107]. This includes the development of low-level drivers for advanced PCI peripheral devices.

Majority of our implementations is oriented towards creation of advanced software toolboxes and packages, connected to advanced embedded digital signal processing hardware [264],[265].

Our research is driven and partially determined by the objectives and requirements, which has to be formulated case-by-case with our partners in EU research and development projects.

Integral part of our work is the active promotion and help to the research groups in the Czech Republic in the area of entering of proposals for the EU funded European research in the area of "Information Society Technology" [81]. This helps not only to the companies. It helps to build

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links between research and potential users. It helps us to specify, what might be needed as the outcome of our work.

3.13 Fast Parallel Computations

The application area of the adaptive signal processing can be broaden substantially by use of fast and parallel computation schemes. The algorithms can be used in low power or high performance industrial applications. This explains the significant effort we put in this direction. In 1999 we got these results:

- A library I/O blocks for the transputer-based PC-acceleration adapters has been finalised [106].
- We finally published our 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. Research is performed within Esprit project 23544 "A High Speed Logarithmic Arithmetic Unit" [108]. This paper received one UTIA internal paper-awards.
- Group has developed a parallel version of the Fault Detection and Isolation Toolbox [248].

3.14 Blind Equalisation and Multiple Access for Wireless Communications

Multiple access interference is present in the wireless communication systems where several mobile users access the base station in the same time. Using subspace-based blind equalisation techniques with linear coding of the transmitted signal, it is possible to solve the concurrent access of multiple users at the same frequency. This result in more efficient utilisation of the available frequency band. High

computational complexity, associated with blind methods, is reduced by use of an approximate recursive algorithm.

Blind channel estimation/equalisation algorithms have been developed and implemented. These algorithms estimate the channel and remove the inter-symbol interference without relying on a training sequence, and increase thus the efficiency of the channel usage. A non-spreading coding scheme has been used to separate different co-channel users without reducing the channel transmission capacity. For verification, the algorithms have been implemented on a DSP system with TMC320C40 signal processors. Compared with the previous solutions, the algorithms developed by the SISTA team have reduced complexity (SISTA is a DSP group at the Kat. Univ. Leuven, Belgium; J. Schier works as a member of this team). The multi-user separation is based on a coding scheme, which allows for parallel non-iterative separation. A demo has been implemented on an experimental DSP system to show the functionality of the approach.

3.15   32bit Logarithmic Arithmetic Simulator

Implementation of floating point algorithms in FPGA (Field Programmable Gate Arrays) creates an open problem. One of possible solutions is the representation of floating point numbers as an integer (fixed point) logarithm (32 bit). Basic arithmetical operations can be performed in this Logarithm Numbering System (LNS) which is suitable for FPGA and ASIC implementation.

A bit-exact simulator of the LNS hardware has been developed [107]. The simulator is a library of C- code Simulink S-function, compatible with Matlab 5.3 and the Real Rime Workshop compiler. C code works identically for the 64-bit

integer variables if compiled as:
- W95/98 SIMULINK S-function;
- W95/98 EXE code created by the RTW from Simulink (compiled by MSCV 6) and
- On 64-bit Alpha AXP platform (Alpha Data Parallel Systems, Ltd.) as the application created by the Alpha AXP target for the RTW (compiled by 3L Parallel C).

This approach leads to a solution, which is suitable to VLSI and FPGA implementation, works with integer operations and logic cells, avoids the need of barrel shift. The 32 bit LNS addition can be performed in time comparable to floating-point 32bit addition without loss of the precision. It needs approximately 32k byte of look-up tables with the word-length 35 bytes. The corresponding VLSI adder can be clocked by 500MHz clock and the latency is just 4 clock cycles. Therefore, the LNS add ALU is a valid candidate for the development of the IP (Intellectual Property) Cores for the FPGA based designs, which need to operate with 32-bit precision range of floating point numbers. The predicted maximal clock frequency is 100 to 200 MHz for the XILINX Virtex devices. The latency 4 clock cycles again. This research is performed under the EU ESPRIT 33544 HSLA Long-term research project, coordinated by the University of Newcastle, UK.

3.16 Support for Simulink and RTW in Real-Time

Simulink is an excellent tool for developing algorithms and simulations but lacks speed and most importantly the ability to run in real-time. Conscious of the growing need for rapid prototyping, the Mathworks developed RTW to quickly turn Simulink diagrams into C code. This is definitely the basis

for producing effective applications in the area of DSP and control. This research has been focussed on development of software supporting the Real-Time Workshop (Matlab 5.3), targeting AD66 ISA and AD66-PCI boards. These boards are using 64-bit Alpha AXP processor, operating on 233MHz/533MHz. Parallel systems with multiple Alpha boards can be created. Alpha nodes communicate via dedicated C44-based comports or Transputer links. The resulting solution is based on compilation of several SIMULINK diagrams for special, dedicated Alpha targets, connected via special I/O-like communication blocks. We have managed to demonstrate that impressive speed- up can be achieved by parallelising and by using operating system free processors. Research resulted in support for 3 particular platforms:

- Parallel systems with AD66 ISA and AD66-PCI boards with DOS interface [265].
- The IDA board. It is a DSP card built around a C31 DSP floating-point Texas Instruments DSP processor TMS320C31, operating on 60MHz.and connected to a host PC via a RS232 link. It is possible to target SIMULINK models compiled using RTW to this board and execute them in real-time. This brings the card real-time and I/O capabilities to SIMULINK models in which the simulated input and output signals can be replaced by real ones. SIMULINK scopes and outputs can be saved into MATLAB .mat files for post-mortem analysis [264].
- Parallel systems with AD66-PCI boards connected by dedicated VxD driver to the Windows Target from Humusoft. The Windows Target serves to provision of the real-time capabilities under Windows95/98 and interface to the low-cost I/O cards (with mainly ISA format). It supports on-line scopes and the interaction with the user. AD66 boards

serve to acceleration of the code under the control of RTW master.

3.17 Support for Czech Participation in EU Research Programmes

The publication "Czech Republic - Information Society Technologies - Contacts 1999" [81] was edited and printed in the co-operation with FEMIRC CZ. It covers: **6** Institutes of the Academy of sciences; **44** Universities, faculties or departments; **22** companies; **21** other institutions and the register of key-words.

The publication was published in an electronic searchable form (search via keywords) on the Czech Idealist-east server at:

`http://www.utia.cas.cz/idealist-east/ISTcontacts/home.htm`

This directory has been advertised (by pointers) at the central EU web pages, IST National Contact Point pages. Book has been distributed (300 volumes) at the IST99 conference in Helsinki, Finland.

This action has been positively acknowledged by the IST committee and (we hope) it could contribute to the success of the Czech small and medium enterprises in future calls of the IST programme.

Other project-partner and public-relation activities:

- Idealist-east CZ database has been created. It includes 430 partners (mainly Czech companies) with active interest in the EU IST programme.
- We have organised 40 individual consultations with some of these companies in 1999.
- R. Matulík and J. Kadlec have participated at the press-conference related to the 40-th UTIA anniversary and pub-

lished 4 popularisation papers in Czech. Papers explain EU Ist programme and present the notebook for the blind).

3.18 Notebook for the Blind

A novel version of a notebook for blind people has been prepared and presented by R. Matulík. The notebook has been selected as one of the two key presentation at the stand representing Czech Republic at the PST99 conference in Helsinki, Finland.

Equipped with synthetic speech and the special Braille keyboard, the notebook performs many tasks in several ways. It can serve as a note-taker. Users can make lists, search through them, remove or add items. They can ask for the time or date. In addition to accurate time, there are also stopwatch, alarm clock and count-down timer functionalities. The telephony directory makes it possible to store names, phone numbers and addresses. The diary maintains users' appointments and reminders of important events.

The notebook can exchange information with a computer via an infrared port or a cable. Hence, a user can work with the notebook anywhere, and later transmit his work to a computer, or receive a large amount of information (e.g. an entire book) from a net-connected computer and read the information with the notebook whenever and wherever he or she likes.

Due to pocket dimensions (180x100x25mm), low weigh (300g) and build-in re-chargeable battery, the user has an aid for instantaneous every-day use with him. The connection to an external disk unit (100Mb ZIP-drive or 1.44Mb floppy) makes the user independent from the computer in accessing his library, placed on the disks.

4 Department of Stochastic Informatics

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Petr Volf	–	survival analysis, nonparametric regression, smoothing methods, statistical reliability testing e-mail: volf@utia.cas.cz

Postgraduate Students:

Lucie Fialová	–	applied information theory
Jaroslav Franěk	–	information theory
Tomáš Hobza	–	nonparametric density estimation and applications in communication networks
Marek Kudrna	–	nonparametric density estimation and applications in stock market

Martina Orsáková   –   regression analysis

Martina Pavlicová   –   spectral theory of random processes

Conferences:

24 lectures, 6 of them invited, have been delivered at international conferences, including

> Inverse Problems in Statistics, Oberwolfach, Germany,
>
> 10th INFORMS Applied Probability Conference, Ulm, Germany,
>
> Measuring Risk in Complex Stochastic Systems, Berlin, Germany,
>
> Summer School, Spetses, Greece,
>
> 4th European Congress SESGE, Valencia, Spain.

Grants and Projects:

V. Beneš: "Integral geometry and statistics of random set components" (GA ČR, 201/99/0269, 1999 – 2001).

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)

J. Á. Víšek: "Combining predictions with the aid of algorithm of decomposition and composition" (GA ČR, 402/97/0770, 1997 – 1999).

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. Smid)
- 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, Prof. A.
  Beirlant)
- 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)
- Ilmenau, Germany (Prof. S. Vogel,
  Prof. E. Liebscher)
- 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)
- Atlanta, U. S. A. (Prof. A. M. Gokhale)

The results of this cooperation are summarized in 9 published papers.

University Courses

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

University of Economics:
Informatics (P. Boček)

Charles University — Faculty of Mathematics and Physics:
Mathematical modelling, Probability theory and mathematical statistics, Invariance principles (V. Beneš); Mathematical statistics, Design of industrial experiments, 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, Econometrics (J. Á. Víšek), Theory of probability and statistics (J. Šindelář).

Czech Technical University
— Faculty of Physical and Nuclear Engineering:
Foundation of the theory of random procesess (J. Michálek),

Information theory (I. Vajda); Statistical Analysis of Data (J. Á. Víšek); Stochastic systems (M. Janžura)

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

As part of teaching activities at the above Universities, nine diploma projects and twenty doctoral theses were supervised, one habilitation theses refereed.

I. Vajda was a member of Scientific Boards of the Faculties of Electrical Engineering and of Physical and Nuclear Engineering, J. Á. Víšek a member of Scientific Board of the Faculty of Social Sciences, Charles University.

Researchers of the Department were members of 3 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 39 papers have appeared during 1999.

Recent Results

4.1 Asymptotically optimal statistical inference based on finite partitions

Computationally simple and at the same time asymptotically efficient and robust minimum ϕ-divergence estimation and testing can be achieved by means of finite quantizations of the observation space provided the quantization size m_n slowly increases with the sample size n. Partitions of this type have been investigated in the previous years as part of the research on Barron nonparametric density estimators. The mentioned new application has been found due to an asymptotic equivalence of various ϕ-divergence statistics established in a joint work of I. Vajda and L. Györfi (TUB Budapest). This equivalence enables to find new asymptotic distributions of ϕ-divergence statistics enabling to evaluate the Bahadur efficiency in the class of nonparametric ϕ-divergence tests. Parametric variants of similar problems have been studied in a joint work with L. Pardo (University of Madrid) and D. Morales (University of Alicante), so far for the partitions with nonincreasing partition size m. It was shown that the inefficiency of the estimates and tests due to the partitioning is practically negligible for moderate m, more precisely that

$$I(\theta) - I_m(\theta) = O(1/m^2),$$

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where $I(\theta)$ and $I_m(\theta)$ are the Fisher informations in the non-quantized and quantized models. The corresponding point estimates and tests are computationally simple and at the same time robust for appropriate functions ϕ [61, 163].

4.2 Statistical event–history analysis

In the field of statistical event-history analysis, the processes of random sums driven by counting processes (compound processes, cumulative processes) were studied. A general model of the intensity depending on the history of the process was considered. An estimator of the cumulative intensity of the process has been derived and its asymptotic properties proven. The goodness-of-fit test was proposed, based on these properties. Further, the model with random effect (frailty model) was used for detection of outlied trajectories and for comparison of two sets of processes. The methods were demonstrated on examples of processes of financial transactions.

Further, a counting process model characterized the reliability (the process of failures) of a system composed from parallel units was investigated, in the framework of load-sharing scheme. The Nelson–Aalen estimator of the cumulative hazard function for components has been derived and its uniform consistency and the convergence of normalized resudual process to a Wiener process has been proved. On this basis, the goodness-of-fit test and the test of homogeneity have been constructed [272, 273].

4.3 Theory and models of random fields

The theory and models of random fields (Ising model, Gibbs field) was studied and used for the solution of problems of

detection of planar objects in random field background, for estimation of parameters of the fields and for the detection of changes of the parameters [97].

Statistical methods of analysis of random fields were applied to the problem of on-line inspection homogeneity and structure of textile materials.

The MCMC algorithms were developed for practical computations, as well as for simulations of random fields [165, 166, 221].

4.4 Estimating the mutual information for the independent component analysis

Independent Component Analysis (ICA) is a name for a wide set of signal processing methods aiming at extracting independent sources solely from observed data that are mixtures of the unknown sources. ICA methods became very successful in many signal processing applications such as the analysis of electroencephalographic (EEG) data, functional magnetic resonance imaging, speech enhancement and image processing. The theory of ICA is based on the concept of statistical independence and mutual information. We studied a novel algorithm for estimating the mutual information, which was recently proposed by Dr. Darbellay [33] in our institute, and we showed how this algorithm can be used directly for 1) separating unkonwn mixture of independent sources and 2) for quality evaluation of other ICA algorithms [250].

5 Department of Econometrics

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Jan Kodera	–	Nonlinear economic systems. e-mail: kodera@nb.vse.cz
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Milan Mareš	–	Fuzzy sets theory, decision-making theory. e-mail: mares@utia.cas.cz
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Vilém Novák	–	Fuzzy set theory, fuzzy reasoning models. e-mail: novak@osu.cz

Karel Sladký	–	Stochastic systems, economic systems, dynamic programming, e-mail: sladky@utia.cas.cz
Andrea Stupňanová	–	Fuzzy sets theory. e-mail: stupnanova@evt.stuba.sk
František Včelař	–	Generalized choice model and Arrow problem in many–valued logical environment.

The Department has concentrated on theoretical economics and econometrics research. Fuzzy approach is used to theoretical framework for decision making. Main research fields are in the following areas:

- Stochastic economics, econometrics and econometric modelling,

- uncertainty processing in expert systems,

- stochastic differential – difference equations with application to capital markets,

- stochastic optimization,

- theoretical fuzzy set approach to decision–making.

Grants and Projects:

- V. Kaňková: *Modelling and Decisions in Time-Dependent Economic Systems* (Grant GA ČR No. 402/98/0742)

- M. Mareš: *Tools and Methods of Mathematical Informatics Cybernetics and Information Transmission* (Key Project of the Academy of Sciences of the Czech Republic No. K 1075601)

- M. Mareš: *Fuzzy Set Theoretical Approach to the Optimization Decision Making in Financial and Investment Policy* (Grant GA ČR No. 402/99/0032)

- M. Mareš: *Homogenous classes of vague data* (Grant GA AV No. A 1075905)

- K. Sladký: *Dynamic Models under Uncertainty in Economics and Finance* (Grant GA ČR No. 402/99/1136)

University Courses:

- *University of Economics, Prague*
  - J. Kodera - Capital Markets

- *Faculty of Social Sciences of the Charles University:*
  - A. Derviz - International Finance A1, A2
  - V. Kaňková - Decision in Economics - Deterministic Optimization
  - V. Kaňková - Decision in Economics - Stochastic Optimization
  - M. Mareš - Game Theoretical Models of Economic Behaviour
  - K. Sladký - Stochastic Processes in Economy
  - M. Vošvrda - Theory of Probability and Statistics
  - M. Vošvrda - Theory of Economic Cycles
  - M. Vošvrda - Theory of Capital Markets
  - M. Vošvrda - Analysis of Derivatives

- *Faculty of Electrical Engineering of the Czech Technical University:*

    - M. Mareš - Theory of Games

Our visitors:

- Dr. Maarten Hendrikus van der Vlerk (University of Groningen, The Netherlands)

- Dr. Willem Klein Haneveld (University of Groningen, The Netherlands)

- Dr. Silvia Vogel (Technical University Ilmenau, Germany)

- Dr. Eckhard Liebscher (Technical University Ilmenau, Germany)

- Dr. Viliam Páleník (Institute of Slovak and World Economics of SAS, Bratislava)

- Ing. Jaroslav Vokoun (Institute of Slovak and World Economics of SAS, Bratislava)

Diploma and Doctoral projects:
Diploma:

- Faculty of Mathematics and Physics of the Charles University (supervisor V. Kaňková - 3)

- Faculty of Nuclear Physics and Engineering of the Czech Technical University
(supervisor M. Vošvrda - 1)

Doctoral:

- Faculty of Mathematics and Physics of the Charles University (supervisor V. Kaňková - 1, K. Sladký - 1)

- Faculty of Social Sciences of the Charles University (supervisor M. Vošvrda - 2)

Conferences Participation:

1. Third GAMM Workshop – Stochastische Modelle und Steuerung, Ilmenau (Germany) March 1999 (Kaňková, Sladký)

2. Seminář o výuce matematicých metod v ekonomii, Liptovský Mikuláš, June 1999 (Vošvrda)

3. Teoria a aplikacie fuzzy mnozin, Kočovce, June 1999 (Mareš)

4. 15th Triennial Conference IFORS, Peking (China), August 1999 (Kodera)

5. Symposium on Operations Research – SOR'99, Magdeburg (Germany), September 1999 (Kaňková, Sladký)

6. EUSFLAT, Palma de Mallorca, September 1999 (Mareš)

7. Mathematical Methods in Economics'99, Jindřichův Hradec, September 1999 (Kaňková, Kodera, Mareš, Sladký, Vošvrda)

8. Sixth International Conference on Parametric Optimization and Related Topics. Dubrovník (Croatia), October 1999 (Kaňková)

9. Future of the Banking – After Year 2000, Karviná, October 1999 (Vošvrda)

10. Fall Econometric Day, Prague, December 1999 (Kaňková, Kodera, Sladký, Vošvrda)

International Cooperations:

Long term cooperation with Department of Economic Sciences and Econometrics – University of Amsterdam, including a visit of K. Sladký to Amsterdam. Two papers finalized in 1999 were accepted for publication in international journals (Journal of Applied Probability, Journal of Optimization Theory and Its Applications)

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.

A cooperation for macroeconomic model constructed for the Slovak Republic and for the Czech Republic was established with the Institute of Slovak and World Economics of Slovak Academy of Sciences, Bratislava.

Public Utility Services:

Three members of the Department (Kaňková, J. Kodera, and M. Vošvrda), were voted fellows of the Czech Econometric Society.

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

M. Mareš is Tresaurer of the Czech Society for Cybernetics and Informatics and member of the American Mathematical Society, member of European Society for Fuzzy Logic and Technologies, Editor-in-chief of journal Kyber-

netika, member of Boards of the research programmes IN-
FRA 2 and Support of Research on Czech Universities.

K. Sladký is Managing Editor of journal Kybernetika.

J. Kodera and K. Sladký are members of the Economic
Sciences Division of the Grant Agency of the Czech Repub-
lic.

V. Kaňková and M. Vošvrda, were voted members of
the Grant Agency of the Academy of Sciences of the Czech
Republic.

R. Mesiar is member of Editorial Board of the Interna-
tional Journal Fuzzy Sets and Systems.

M. Vošvrda has also participated in a TEMPUS program
for forming lectures on Capital Markets at Universities in
Europe.

5.1 Macroeconomic Modelling

A macroeconomic modelling describes the short-run evolu-
tion of an open economy in terms of two aggregate domestic
commodities: a physical good and labor. This approach
defines for each period the supply and demand of the phys-
ical good and of labor. The interaction of supply and de-
mand on the two markets determines simultaneously output
and employment and hence the rates of capacity utilisation
and of unemployment. These variables in turn trigger price
and wage adjustments. The evolution of prices and quanti-
ties feeds back into the determinants of supply and demand,
thereby closing the model [242].

5.2 Stochastic finance

A discipline studying the price formation in financial mar-
kets under uncertainty. Historically, the first group of fi-

nancial theory models derived no-arbitrage pricing results in complete markets. The next generation of models dealt with stochastic general equilibrium prices in incomplete markets. A particularly productive segment of both groups is formed by models of derivative pricing. In the years 1995-99, it was mainly worked on applications of the stochastic finance theory to problems of international macroeconomics, particularly the exchange rate determination [42]

5.3 An Economic Uncertainty Principle on Capital Markets

One of the central tenets of modern financial economics is the necessity of some trade-off between a risk and an expected return. It is generally known the price of interest-bearing securities such as bonds rises when rates fall, and vice versa. If a security's expected price change is positive, it is needed a reward to attract investors to hold the asset and bear the corresponding risks. If an investor is sufficiently risk averse, he might gladly pay to avoid holding a security, which has unforecastable returns. It probably holds: you cannot understand a social fact and make money from it at the same time. [278]

5.4 Uncertainty Cooperation Models

Fuzzy Set Theoretical Models

The research of the coalitional games with vague idea about the expected pay-offs was continued especially by the detailed comparison of both existing formal approaches to the fuzzification of the deterministic models of such games. Namely, in the deterministic case there exist two basic models of cooperation. One of them supposes the existence

of a universal representative of utility which can be trans-
ferred among players (so called transferrable utility games
or games with side-payments), and a more general approach
not accepting the above assumption, due to which the coali-
tion members only coordinate their strategies and each of
them accepts his own income (so called non-transferrable
utility games or games without side-payments). Each of
these basic models can be fuzzyfied in a different way. In
the former model, the expected coalitional incomes are rep-
resented by real numbers and its fuzzy theoretical modifica-
tion means to substitute them by fuzzy numbers. The latter
model represents the possible results of the game by a set
of real-valued vectors (called imputations) and their fuzzifi-
cation means to substitute these deterministic sets by fuzzy
sets. Both approaches lead to rather different results regard-
ing the properties of, e.g., superadditivity concept, core-like
solution of the game and some other formal concepts of the
game theory. In this year, a special sort of coalitional games
(called linear coalitional games) which can be in an equiva-
lent way described by both models - with and without side-
payments. Their fuzzification offers a possibility to compare
in an exact way, both formal fuzzy game theoretical models
and their results. This research was realized partly in co-
operation with professor Milan Vlach from Japan Advanced
Institute for Science and Technology [174], [170], [173], [171],
[172], [175], [178].

Another part of the research was focused to the pro-
cessing of fuzzy data represented by fuzzy numbers and used
as inputs of originally deterministic or statistical algorithms.
The results of this research mainly regard the representa-
tion of fuzzy numbers by means of triangular norms (t-
norms) whose properties were intensively investigated and

some significant relations to the fuzzy measure theory and related topics were derived [184], [185], [186], [187], [188], [189], [190], [191]. Further properties were found for simple statistical processing of fuzzy numbers like fuzzy regression analysis and the theory of time-series with uncertain elements. This direction of the research includes also the continuing investigation of so called generated fuzzy quantities or verbal quantities modelling the computational properties of quantitative data characterized by vague verbal expressions [177], [176]. The investigated model of verbal quantities was suggested in the previous years, and in this year some of its properties were proved. It was also shown that the computations based on the suggested model of fuzziness of real data are significantly simplified.

Fuzzy logic in narrow sense

There is a significant progress especially in fuzzy logic in narrow sense. It seems that the crucial parts of fuzzy logic in narrow sense are now more or less concluded since the algebraic structures suitable for representing truth values of fuzzy logic are being intensively studied and a lot of results have been obtained. Among them, two structures play crucial role, namely MV- and BL- algebras. The latter are algebras characterizing the, so-called, t-norms, which are generalizations of the conjunction operators. The former are non-trivial generalizations of Boolean algebras. It can be stressed that MV-algebras allow the closest and at the same time non-trivial departure from classical logic. Fuzzy logic based on them made possible to prove generalization of classical significant theorems, such as deduction, reduction, Hilbert-Ackermann, Herbrand, and other ones. [204], [202], [203].

5.5 Monotonicity and Comparison Results for Nonnegative Dynamic Systems

Monotonicity and comparison results are known to be most useful for the qualitative analysis of Markov chain applications. In this research, the extension of such results was studied for the more general class of dynamic systems governed by nonnegative matrices.

Both the discrete-time and continuous-time case were investigated. It was shown that monotonicity and comparison results for marginal and cumulative reward expectations of Markov chains can be extended to this more general nonnegative case. For the continuous-time case an extended uniformization result is hereby developed which is of interest in itself [257].

5.6 Sensitivity analysis of Semi–Markov Processes

In sensitivity analysis of semi–Markov processes we study influence of perturbations (i.e. small changes) both of the transition probability matrix of the underlying Markov chain and the holding time distribution – but no other parameter of the perturbed process, or the limiting distribution of the considered semi–Markov process.

In [240], [239] perturbation formulas for discrete–time Markov chains were extended to the case of semi–Markov processes. Moreover, it was shown how these formulas read for the case of continuous–time Markov chain.

5.7 Stochastic Programming and Decision in Economy

Many applications lead (from the mathematical point of view) to optimization problems depending on a probability

measure. This type of the problems represents an essential part of the field of the stochastic programming. In the literature a great attention was paid to the investigation of the "theoretical properties" of the individual problems types. Furthermore there statistical estimates (in the case when the theoretical measure is not completely known) and connected stability problems were investigated as well as numerical possibilities of the solution together with a construction of solution algorithms. All these question were discussed for one–stage (static) models as well as for their dynamic versions (multistage stochastic programming problems). However, in spite of this fact, many very important problems are not still satisfactorily solved.

The main effort (in the year 1999) was paid to the multistage stochastic programming problems. In particular, the aim was to apply some of the known stability results from one–stage stochastic programming theory to the multistage case. To this end, first, it was necessary to continue in the investigation of the individual (decomposed) optimization problems [110]. Furthermore, it seemed reasonable to restrict the investigation to a special (rather important from a practical point of view) type of the Markov dependenc. The newly achieved stability results were, furthermore, employed to the construction of approximate methods of the solution. An upper bound of error approximation was determined for this approach [111].

Furthermore, the problem of unemployment and restructuralization was analysed in [112]. Two multistage models of economic and social problem of unemployment and restructuralization were constructed [113]. They correspond to the multistage stochastic programming problems with individual and joint probability constraints.

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P. Somol	-	Statistical Pattern Recognition
R. Vrňata	-	Statistical Feature Selection
P. Žid	-	Image Segmentation
V. Havlíček	-	Texture Synthesis
P. Paclík	-	Statistical Pattern Recognition

Grants and Projects

- 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

- M. Haindl, "Virtual Reality"
  Grant of the Ministry of Education; No. OK276

- M. Haindl, "Virtual Reality"
  Hewlett Packard Grant; No. ISE-86L8-13

PhD Projects:

- Faculty of Mathematics, Charles University
  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 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

- Faculty of Transportation, Czech Technical University, Prague
P. Paclík: "Kernel Classifier for Road Signs Recognition Problem"
Supervisor: J. Novovičová

MSc Diploma Projects:

University Courses:

- Faculty of Electrical Engineering, Czech Technical University
M. Haindl: "Pattern Recognition"

- Faculty of Management, University of Economics, Prague
P. Pudil: "Statistics for management"
P. Pudil: "Applied artificial intelligence for management"

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  J. Novovičová: "Mathematical Statistics"
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International Co-operation:

- Representation in international bodies:
  M. Haindl — Chairman of the IAPR Publication and Publicity Committee
  M. Haindl — member of the ERCIM - Editorial Board
  P. Pudil — Chairman of the IAPR Technical Committee "Statistical Techniques in Pattern Recognition"
  P. Pudil — member of the IAPR Governing Board (representative of the Czech Republic)
  P. Pudil — External PhD examiner for Cambridge University

- Co-operation on statistical approach to pattern recognition:
  P. Pudil, J. Novovičová, J. Grim — University Surrey, GB; University of Valencia, Spain, University of Hokkaido (joint research project), University of Salzburg (joint research project)
  P. Pudil — University of Cambridge, GB

- Co-operation on image data modeling:
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Conferences

- International Symposium on Pattern Recognition "In Memoriam Pierre Devijver", Brussels, February 1999 ([225]).

- 4th System Science European Congress, Valencia, Spain, 1999.([54])

- 11th Scandinavian Conference on Image Analysis, Kangerlussuaq, Greenland, 1999 ([63, 211]).

- Pattern Recognition in Practice VII, Vlieland, June 1999 ([243]).

- 17th International Conference on Mathematical Methods in Economics '99, Jindrichuv Hradec, September 1999.([56, 224]).

- Third International Conference on Computational Intelligence and Multimedia Applications 1999, New Delhi, India, September 1999 ([223]).

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 aim of of the Road Sign Recognition System is to recognize the road signs in the traffic scene and so help the human driver with the decision making process. The new adaptive kernel classifier for road signs recognition based on the kernel estimation of class-conditional densities has been developed. It operates with any ideogram-based road signs. It uses the apriori information about road signs grouping for the problem decomposition. The Laplace kernel classifiers are on tree. The smoothing parameters of the kernel are optimized by the pseudo-likelihood cross-validation method [211].

Significant results have been achieved by successful applications of feature search methods in the field of economics. Floating search methods have been applied to the problem of optimizing multiple stepwise regression. The new methodology has been tested on two separate forecasting problems from the field of macroeconomics and the results have been presented at two international conferences [224, 223].

Two new methods of adaptive floating search for feature selection have been developed [243]. Owing to a more thorough search than classical floating search, they have a potential of finding a solution even closer to the optimal one. The trade-off between the quality of solution and the computational time can be controlled by users setting of certain parameters.

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6.2 Probabilistic Neural Networks

A a new approach to structural optimization of probabilistic neural networks has been proposed [54] making use of an idea originally designed for multivariate pattern recognition. It is based on finite mixtures including binary structural parameters. By means of a special "background" substitution technique the evaluation of components can be confined to "relevant" subspaces only. In this way the receptive fields of neurons can be reduced to arbitrary subsets of input variables. The optimal choice of input variables is controlled by an information criterion.

In a paper to be presented at the conference on Neural Computation in Berlin, Mai 2000 the above method is applied to recognition of totally unconstrained handwritten numerals from the database of Concordia University in Montreal. The problem was solved in the original space of nonreduced dimension N=1024 (binary 32x32 raster). Unlike similar published solutions we didn't use any preceding feature extraction or feature selection which may essentially improve the classification accuracy. In computational experiments with randomly initialized mixture models we obtained repeatedly recognition accuracy which is comparable with the results reported in literature.

6.3 Markov Random Fields

The theory of random field models is one of the basic tools for modeling spatial, temporal and spectral relations in complex pattern recognition and image processing tasks. Different Markov random field models, simultaneous autoregressive models, and problems with their parameter estimation,

synthesis and optimal contextual support set detection were our primary research interest. Research results were applied in texture segmentation [63], texture mapping [64], shape and texture data fusion [66], image restoration, and in natural colour texture synthesis [65] applications. We have proposed a novel recursive Gaussian Markov random field pseudolikelihood parameter estimator [63] which was applied in the colour texture segmentation algorithm [63], [65]. This algorithm does not require any knowledge about textures present in a segmented scene and is an order of magnitude faster than the best previously published algorithms of the similar type. Two original image restoration algorithms using a combination of causal and non-causal weak Markov models were introduced in [62]. Both methods are fully adaptive, numerically robust but still with moderate computation complexity. A multiresolution approximation of a non-causal Gaussian Markov colour texture model together with its parameter estimation and synthesis was proposed in [65]. This model which enables to describe complex spatial relations due to independent Markov submodels for single spectral and frequency factors, was verified in the Internet distributed form of Java applets [65].

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Grants and Projects:

- J. Flusser - Computer Aided Fractography (Grant Agency of the Czech Republic, No. 106/97/0827 – jointly with the Faculty of Nuclear Science and Physical Engineering, CTU)

- J. Flusser - The influence of a rearing environment of the welfare of dairy cows evaluated using thermographic methods (Grant Agency of the Czech Republic, No. 523/99/1489 – jointly with the Research Institute of Animal Production)

- T. Suk - Combined invariants and their using for recognition of 2-D objects (Grand Agency of the Czech Republic, No. 102/98/PO69, post - doctoral project)

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Jan Flusser	–	"Digital Image Processing" at the Faculty of Mathematics and Physics, Charles University, Prague.
	–	"Image Processing and Pattern Recognition", Faculty of Nuclear Science and Physical Engineering, CTU, Prague.
Dana Klimešová	–	"Geographical Information Systems and Image Processing" at the Faculty of Economics and Management, Czech University of Agriculture, Prague.
Stanislav Saic	–	"Image Processing" at the Faculty of Science, Charles University, Prague.
Barbara Zitová	–	"Image Processing and Pattern Recognition" at the Veracruz University, Mexico.

The research activity is focused on the following areas:

- Theory of the invariants

- Recognition of distorted images and patterns

- Texture and context analysis

- Image restoration

- Applications in remote sensing, astronomy, medicine, material science, geodesy and geophysics

7.1 Robust Detection of Significant Points in Multiframe Images

Detection of significant points is an important step in image processing and computer vision. It provides input information for further operations like image registration, image fusion and time-sequence analysis, among others. Significant points (SP) are salient points which are easy to identify in the image - corners, line intersections, T-junctions, etc.

The multiframe version of the SP detection looks for the significant points in two or more images of the same scene. Multiframe SP detection methods must fulfill condition of repeatability - results should not be affected by imaging geometry, radiometric conditions and by an additive noise and sets of significant points detected in all frames should be identical. Since the last requirement is not realistic in practice, "maximum overlap" is usually required instead of the identity. An applicability of detection methods depends on their ability to fulfill 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 individual frames may be rotated and shifted with respect to one another, they may be degraded by a linear shift-invariant blur and an additive zero-mean noise may be present. Our primary motivation comes from the area of remote sensing, where the registration of images with such kinds of distortions is very frequent task. Under these conditions it is impossible to achieve identical point sets in different frames. Here, the condition of repeatability is weakened to the point sets overlap of at least 50 %, which is, however, sufficient for most applications.

Generally, SP detectors can be divided into two groups. The first of them uses directly the grey-level image information for SP detection (they look for the extremes of the curvature of a plane curve perpendicular to the gradient of the image function, of the Gaussian curvature of the image function, etc.). The second group of SP detectors localizes significant points using the output of the edge detector, ran on the original image. Existing methods are designed mainly for the single-frame case but they can be usually used in the multiframe case, too. But their repeatability is not sufficient in the case of blurred frames.

We propose parametrical SP detector for the multiframe case. Our parametrical approach can handle differently blurred images. Points, which belong to two edges with an angle from the interval $[\pi/2 - d_a, \pi/2 + d_a]$ (d_a is user defined parameter) in between regardless of its orientation are understood here as significant points. Our method is based on this definition.

The significant points are detected by means of the information about the number of edges passing through each pixel and about the angle between edges. This information is acquired from the number and distribution of local sign changes in the difference between the image function and its local mean values. Detailed description of the method can be found in [284]. Application of the proposed SP detector for the image registration of satellite images is described in [48].

7.2 Image Invariants to Linear Filtering

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 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 $f(x, y)$.

A new approach we proposed 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.

Earlier (1995-97) 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. Recently we have generalized these invariants to be also independent of rotation and scaling of the image. Their definition, proof of invariance and applications in satellite image registration can be found in [47] and [48].

7.3 3-D Hydrodynamical Modelling of Viscous Flow Around a Rotating Ellipsoidal Inclusion

In ductile shear zones and in metamorphic rocks in general, the geometry of fabric is a valuable source of information on the kinematics and dynamics of flow. To understand the fabric development, structural geologists use numeric al or analogue modelling of behaviour of rigid objects embedded in a viscous matrix. Numerical models are based on continuum mechanics and, with more or less accuracy, describe the motion of a rigid body and/or the flow around it. The aim of our work is the presentation of a procedure based on the approach of Jeffery that enables numerical modelling of the flow around rigid ellipsoidal inclusions. Jeffery's equations were re-developed and corrected, and we found an efficient way to compute the elliptic integrals that are needed for the solution. The model of Jeffery is based on some assumptions (slowly moving Newtonian fluid, non-interacting particles) that are not always strictly valid in nature. Despite this fact, the model represents a valuable tool for studying the behaviour of rigid objects in a viscous matrix and the

number of its applications will probably increase. On the field of geosciences, our approach can be used for modelling the development of inclusion trails in porphyroblasts. Final results can be found in [101] and [100].

7.4 Bayesian approach to collocation

Collocation is well-known method for estimation and prediction problems since the early 70's. Least-square method as the methodological basis of collocation can be easily generalized with the aid of Bayesian statistics to deal properly with nonlinear models and non-normal probability distributions of measurement errors. This generalization is extended to embrace collocation as well. Collocation is actually explained in terms of probability theory in the contribution. The principle of this approach is based on a bit non-traditional interpretation of the fundamental equation of collocation ($\mathbf{Ax} + \mathbf{l} = \mathbf{v} + \mathbf{s}$, where $\mathbf{x}$ is a vector of estimated parameters, $\mathbf{v}$ is noise and $\mathbf{s}$ is a signal).

Signal $\mathbf{s}$ is considered to be a random vector which quantifies the errors of the linearization of an original relationship between estimated and observed physical quantities. When this original nonlinear relationship is approximately known (e. g. at some discrete points), then probability distribution of signal $\mathbf{s}$ can be derived with use of a prior probability distribution. An effective method for determination of this probability distribution and its covariance matrix is presented in the contribution. The suggested method is compared to the traditional approach with covariance function that depends on the distance of measurement points. Information gain of the results of estimation or prediction is discussed from the viewpoint of information theory.

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7.5 Multichannel Image Restoration Techniques

By the term multichannel (MC) image we mean multiple image planes (channels) that are typically obtained by an imaging system that measures the same scene using multiple sensors and/or an imaging system that measures the same scene at different time instants. In the former case we talk about wave radiometric images and multispectral images, where the channels are different frequency bands. Color images represent a special case of great interest. In the latter case the output of an imaging system is a image sequence, where the different time frames represent the channels. The channels do not have to be necessarily different frequency bands or time samples, but they could also be different resolution representations of the original image. This is for example the case of reconstruction of a high-resolution image from multiple low-resolution images or a wavelet subband decomposition of a single-channel (SC) image.

In many imaging applications including astronomical speckle images, remote sensing, and medical imaging, an observed image can be accurately represented by the sum of additive noise and the 2-D convolution of the true image with a linear shift-invariant blur, also known as the *point-spread function* (PSF). The blurring function results from a relative motion of measured objects to imaging systems, defocused lenses, and a turbulence of a media in which imaging systems measure (atmospheric turbulence), among others. The noise term is not negligible. Common types of noise are electronic, photoelectronic, film grain and quantization noise. The problem of restoring the the original image requires the *deconvolution* of the PSF from the degraded image.

We can deal with the MC restoration problem on a SC level. Thus restoring individual channels separately but be-

cause MC images exhibit strong between-channel correlations this approach is not what we want. All the channels of the MC image should be processed as one entity. There are two advantages of restoring images in a multichannel framework. First, the cross-correlation terms are exploited to achieve better restoration results. Second, the MC framework allows for the possibility of having cross-channel degradations. Such cross-channel degradations may occur in the form of channel crosstalks, leakages in detectors, and spectral blurs. The phenomenon of spectral blurs is also called the chromatic aberration or dispersion and occurs in certain devices, e.g. optical fibers.

An important assumption for a good restoration of MC images, that is not present in SC processes and that must be satisfied, is the channel registration. Before the restoration process can take place the image channels must be properly registered. In the case of multispectral images we often assume that the assumption is automatically satisfied, but in the case of image sequences registration could be a serious and very difficult task.

An overview of MC restoration techniques can be found in [246].

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