ACTIVITY REPORT '2000

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GENERAL

Institute of Information Theory and Automation is a research institute of the Academy of Sciences of the Czech Republic. It is 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 2000. 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 eight 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.

Institute of Information Theory and Automation
Academy of Sciences of the Czech Republic

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The Institute of Information Theory and Automation (ÚTIA) was established in 1959 as a merger of two academic laboratories: the Department of Information Theory of the Institute for 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. Main developments in the 1990s are in recursive nonlinear estimation, usual data reconstruction 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-

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 University of Economy, 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

- 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.

and participated in the organisation of numerous other conferences.

Among others, the Institute is an organizer or coorganizer of

- 1st IFAC Symposium on Systems Structure and Control, Prague, August 29–31, 2001
- International Conference on Artificial Neural Networks and Genetic Algorithms. Prague, April 10–14, 2001

Contents

1 Department of Decision–Making Theory

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Grants and Projects:

- 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 diff. equations and inequalities. (T. Roubíček)
  - Modern optimization theory. (J. Outrata)
- Faculty of Informatics and Statistics of the University of Economics

  - Knowledge representation and processing. (R. Jiroušek)
  - Bayesian networks. (R. Jiroušek)
  - Intelligent systems. (R. Jiroušek)
  - Logics. (J. Vejnarová)

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

Our Visitors:

- Dr. Barbara Vantaggi (Università la Sapienze, Roma)
- Prof. Andreas Prohl (University of Kiel)
- Prof. Dr. I. Singer (Math. Inst. of the Romanian Academy of Sc.)
- Prof. René Henrion (WIAS - Berlin)
- Dr. R. Bouckaert (Crystal Mountains, New Zeland).

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:

- mathematical optimization,
- differential equations,
- probabilistic decision support systems,
- artificial intelligence and alternative calculi.

1.1 A subdifferential criterion for calmness of multifunctions.

Calmness of a special class of multifunctions plays an important role in optimization, in deriving optimality conditions, in constructing efficient error bounds for difficult constraints, and in analyzing the stability of obtained solution with respect to small perturbations of input data. In [75] a new calmness criterion has been derived which is weaker (less restrictive) in comparison with standard criteria obtained via the so-called Aubin property or via the upper Lipschitz continuity. By using this new criterion one could weaken e.g. the well-known Mangasarian-Fromowitz constraint qualification, or furnish a new stability condition for perturbed nonlinear complementarity problems. The criterion is quite workable, but some questions remain still open; for instance a suitable generalization to an infinite dimensional setting.

1.2 Evolutionary models microstructures.

Many problems studied in modern physics and engineering by continuum-mechanics methods exhibit a multilevel structure. Behaviour on micro- or meso-scopical level influences essentially behaviour on macroscopical level. Therefore the microstructure arising on lower level cannot be neglected. This requires special analytical and numerical treatment, and great attention to microstructure modelling has been devoted worldwide during past decades.

We used so-called Young measures involved in a generalized configuration of a system q to describe a microstructure in selected concrete situations. A nontrivial task is to determine evolution of q that would agree with experiments. Here, evolutionary variational inequalities with two nons-

mooth nonlinearities of the type $R'(\frac{dq}{dt}) + V'(q) + N_Q(q) \ni f(t)$ have been used to describe the evolution of a microstructure in shape-memory alloys and in ferromagnetics. Hysteretic behaviour typical for both cases required a usage of nontrivial mathematical theory using, in particular, finitely-additive measures. In most cases, numerical experiments have been performed. A survey paper [188] monitores some models used for martensitic crystals with shape memory.

1.3 Bauer's maximum principle and hulls of sets.

The basic property of any convex continuous function defined on a convex and compact set in R^n is that it attains its maximum at some extreme point of this set. This assertion is called *the Bauer maximum principle*. One consequence of this principle is the Krein-Milman theorem saying that compact convex sets in R^n are closed convex hulls of their extreme point. It can also be used, for instance, to show the existence of solutions to some nonconvex problems in the calculus of variations and optimal control theory. In [127] we derive a version of Bauer's maximum principle for polyconvex, quasiconvex and rank-one convex functions defined on compact sets in $R^{m\times n}$, where $R^{m\times n}$ is identified with the Euclidean space of real matrices $m \times n$.

Then we apply obtained results to cones of polyconvex, quasiconvex and rank-one convex functions which are of importance in the calculus of variations. In the second part of the paper we discuss some properties of sets of quasiconvex and rank-one convex extreme points. In particular, we show that that they are generally different and that quasiconvex extreme points, likewise quasiconvex functions, are not invariant under the composition with affine mappings which map rank-one matrices into rank-one matrices.

1.4 Methods of description of conditional independence structures

In [175] quite general graphical method of description of conditional independence structures over finite number of variables was developed. The method is based on regular *annotated graphs*, that is undirected graphs whose nodes correspond to variables and whose edges are annotated by sets of variables. Formal independence model induced by a regular annotated graph is shown to comply with graphoid axioms. The new graphical method of description of probabilistic conditional independence structures generalizes clasical methods which use undirected graphs, acyclic directed graphs and chain graphs. The results of [175] were described in details in 1999 activity report.

The paper [211] reviews various mathematical methods of description of probabilistic conditional independence structures, including a specific non-graphical method which uses certain integer-valued discrete functions called *structural imsets*. This method makes it possible to describe any probabilistic conditional independence structures (unlike various graphical methods). The problem of computer implementation of this method in case of five variables motivated the research activity described in the report [212]. A computer program which realizes the respective facial implication of structural imsets and can be used for automatic derivation of formal properties of probabilistic conditional independence was developed.

1.5 Lengths of semigraphoid inferences

Where N is a finite set, semigraphoids are special sets of triples (I, J, K), $I, J, K \subseteq N$ disjoint, that mimic condi-

tional independences. Semigraphoids are discrete structures behind the conditional independence modeling in philosophy and artificial intelligence: the incidence of (I, J, K) to a semigraphoid is interpreted as 'conditional independence of I and J given K'. Semigraphoids underpin also manipulations with the conditional independence constraints of numerous models of multivariate and Bayesian statistics.

In [147] a subset $\mathcal{L}$ of a semigraphoid $\mathcal{K}$ over a set N of n elements was constructed in such a way that starting from $\mathcal{L}$ it is necessary to apply semigraphoid axioms recursively $2^{n-2}-1$ times to arrive at $\mathcal{K}$. This is first known example of exponentially long semigraphoid inference. The main ideas underlying this result were to work with a local inference, keep track on its relation to a global inference, and to redefine semigraphoids as subgraphs of special regular graphs with colored edges. The local inference was then interpreted as addition of edges with special colors. Graphoids, pseudographoids and their duals were studied from this point of view as well.

1.6 Composed multidimensional models

Large multidimensional distributions (both probabilistic and possibilistic) can be effectively represented only when they possess special properties enabling them to be represented by a reasonable number of parameters. For finite-valued variables, for which we restrict our attention, it means that they have to have special dependence structures. In contrast to great majority of other approaches, which represent these structures with graphs, the considered technique is procedural and describes a way how a multidimensional distribution is computed from a system of low-dimensional distributions,

and therefore need not represent the dependence structure explicitly.

In previous papers special operators of *right composition*, that construct a new distribution $P_1 \triangleright P_2((X_i)_{i\in K_1\cup K_2})$, from two distributions $P_1((X_i)_{i\in K_1})$ and $P_2((X_i)_{i\in K_2})$, were introduced. Applying this operator iteratively to a sequence of low-dimensional distributions one obtains multidimensional distribution $P_1 \triangleright P_2 \triangleright \ldots \triangleright P_n$, which is defined for variables $(X_i)_{i\in K_1\cup K_2\cup\ldots\cup K_n}$. Regarding the fact that the operator $\triangleright$ is neither commutative nor associative, one has to apply the operators from left to right. Therefore, to construct a multidimensional distribution it is enough to determine a sequence of low-dimensional distributions, called *generating sequence*. Among them, special role is played by the sequences called *perfect*. These are those for which all $P_1, P_2, \ldots, P_n$ are marginal to the joint distribution $P_1 \triangleright P_2 \triangleright \ldots \triangleright P_n$. In addition to this, it can be shown that the class of belief networks (Bayesian networks in probabilistic setting [92], possibilistic belief networks in possibilistic framework [219]) is equivalent to the class of perfect sequences in the following sense:

1. If $P_1, \ldots, P_n$ is perfect then there exists a belief network representing the distribution $P_1 \triangleright \ldots \triangleright P_n$ such that for each variable X_j there exists $k \in \{1, \ldots, n\}$ such that
$$cl(X_j) = (\{X_j\} \cup pa(X_j)) \subset (X_i)_{i\in K_k}.$$
2. For each belief network one can construct a perfect sequence $P_1, \ldots, P_n$ such that each $(X_i)_{i\in K_k}$ equals some $cl(X_j) = \{X_j\} \cup pa(X_j)$ and $P_1 \triangleright \ldots \triangleright P_n$ equals the distribution represented by the belief network.

In other words, there are simple procedures transforming an arbitrary belief network into a perfect sequence and vice

versa; and the distributions defining both structures (i.e., respective conditional distributions defining the belief network and distributions from the generating sequence) are of the same dimensionality.

One of the main results achieved in this field in 2000 [93] describes how to compute generating sequences defining marginal distributions of the distribution $P_1 \triangleright P_2 \triangleright \ldots \triangleright P_n$, i.e. how to define distributions $Q_1, Q_2, \ldots, Q_n$ such that

$$P_1 \triangleright P_2 \triangleright \ldots \triangleright P_n((X_i)_{i \in K_1 \cup \ldots \cup K_n}) = Q_1 \triangleright Q_2 \triangleright \ldots \triangleright Q_n.$$

2 Department of Control Theory

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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, Convex Optimization and Polynomial Matrices in Control (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)
- M. Šebek, Algorithms and Software for Analysis and Synthesis of Linear Multivariable Control Systems (Czech–Greek 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 Nonlinear Systems (graduate).
- 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.

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).

Our Visitors

- S. Bittanti, Politecnico di Milano, I,
- F. A. Cuzola, Politecnico di Milano, I,

- A. Dzielinski, Warsaw University of Technology, P,
- E. Fornassini, University of Padova I,
- D. Henrion, LAAS-CNRS Toulouse, FR,
- S. Kozka, Slovak University of Technoogy, SK,
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- H. Kwakernaak, University of Twente, Enschede, NL
- U. Nurges, Tallinn Technical University, Estonia,
- J. Ruiz, CINVESTAV del IPN, Guadalajara, MEX,
- U. Shaked, Tel Aviv University, Israel,
- S. Shankar, Univeristy of Bombai, Indie,
- M. Sternad, Uppsala Universitet, S,
- A. Vardulakis, Aristotle University of Thessaloniki, Greece,
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- R. Ylinen, Univeristy of Oulu, Finland.

Representation in International Societies

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

D. Henrion – Member of the Conference Editorial Board of the IEEE CSS;

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;
– Executive Committee member of the Czechoslovakia IEEE Section;
– Executive Committee member of the Central European Chapter of the IEEE SME.

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;

D. Henrion – 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 Control of Linear Systems Subject to Input Constraints

The problem of control constraints appears in most practical control systems. Due to technological and safety reasons, the actuators cannot drive an unlimited amount of energy to the control plant this fact can be translated into bounds on control and state variables.

Control systems are often designed using linear control theory. In general, this kind of design does not directly consider amplitude limitations on the control inputs. Then, the presence of input bounds can be a source of parasitic equilibrium points and limit cycles, or can even result in an unstable behavior.

Control limitations can be handled implicitly, or a posteriori, using anti-windup strategies. Alternatively, input constraints can be handled explicitly, or a priori, pursuing the saturation avoidance or the saturation allowance approaches.

The research reported here focuses on preventing the saturation to occur. The closed loop system therefore stays within the domain of linear behavior. Local stability is guaranteed for an admissible region of initial states. For convenience, a polyhedron region of initial states is considered.

Two problems are solved: (1) find a controller such that a given linear plant subject to input constraints is stabilized for initial states within a given polyhedron region, and (2)

find a controller and a polyhedron region as large as possible such that a given linear plant subject to input constrains is stabilized for initial states within this region. Discrete-time controls are considered.

Rather than applying standard state space techniques, a transfer function approach is pursued. First, the Youla-Kučera parametrization of all linear controllers that stabilize the given plant is invoked. Then the geometric properties of polyhedra are used to come up with a linear programming formulation of the constrained stabilization problem. Problem (1) is shown to be a mere feasibility problem. Under the proviso that homothetic polyhedra of initial states are consid optimization problem in the scaling factor.

The solution obtained is a fine example of the power of the transfer function methods. The solution is simple, the computations required are standard. The solution is conservative, however, due to the simplifications described. Compared to the state space methods, one can easily find a dynamic controller. The order of the controller, however, may be high.

2.2 Polynomial matrices and linear matrix inequalities

Pursuing the research endeavor of the previous year, we investigated further the application of convex optimization techniques (more specifically optimization over linear matrix inequalities or LMIs) to solving control problems involving polynomial matrices. A brief illustrative survey of the most recent results in the domain was presented in [73]. A relaxation heuristic based on LMIs was proposed in [69] to solve the difficult problem of stabilization of a linear system with a controller of fixed order whose coefficients are restricted to given intervals, a design problem dual to the problem of

finding a controller stabilizing a set of linear systems whose uncertain coefficients are restricted to given intervals. Application of LMI techniques to the study of location of zeros of polynomial matrices in arbitrary regions of the complex planes was described in [67] Optimization over LMIs was also found useful when stabilizing linear systems subject to hard constraints on the input signal, a problem having numerous practical applications. Following the preliminary results on scalar plants described in [70], a more general polynomial approach to the constrained stabilization of multivariable systems was proposed in [74]. Finally, the application of LMI techniques to the robust stability of a polytope of polynomial matrices was proposed in [66], [66].

2.3 Numerical methods for polynomial matrices

A polynomial approach (spectral factorization and Diophantine equations) to solving the H_2 control problem was recalled in and illustrated with numerical examples and Matlab scripts calling macros of the Polynomial Toolbox.

The problem of extracting from a polynomial matrix a factor featuring a given subset of finite zeros was studied in [71] Extension to the extraction of infinite zeros was later on developed.

An original method has been develod for spectral factorization of polynomials. The method is based of Fast Fourier algorithm and therefore is very fast. It is also very reliable and suitable for polynomials of high degrees (1000 and more).

2.4 Robust output regulation of nonlinear systems

The problem of output regulation is the one of forcing a given output to track desired reference and/or reject an undesired perturbation, both of them given via another dynamical system, called as the exogeneous system. Robust case deals with influence of unknown references. Such a problem is usually solved via dynamical error feedback. The corresponding necessary and sufficient condition is the solvability of the so-called regulator equation and the immersion of a certain nonlinear system with output given by the above mentioned regulator equation into a system having special stabilizability and detectability properties. Those conditions are known to be rather peculiar ones and for the general class of systems no constructive procedure to check them exists. Classes enabling the constructive solution of the problem are rather narrow. Moreover, the situation is complicated by those detectability and observability conditions.

Therefore, two different aspects were adrresed.

First, [168] introduces dynamical error feedback combined with the exo-state measurements. This enables to formulate the solution in terms of the so-called generalized immersion. The latter one is weaker as demonstrated in some examples, including case study of inverted pendulum.

The problem of robust output regulation of systems having different measured and controlled outputs is solved in [25] The motivation is to deal the situation when the system and exosystem do not have sufficient detectability properties from the error of regulation. In this situation, the straightforward idea is to choose some additional measured output having good detectabilty properties. This case is being complicated when robust aspects are included since a straightforward combining of both output information typically leads

to lack of robustness.

Introducing a special algorithm to combine the above mentioned information, the robust dynamical feedback is obtained.

Illustrative examples are included.

3 Department of Adaptive Systems

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Year 2000 brought a lot of personal achievements and changes. Mgr. L. Jirsa [94], Ing. L. Tesař [215] and Ing. P. Ivanova defended their thesis. L. Jirsa got also the degree RNDr. We hope that N. Khailova and M. Valečková will submit their thesis soon. New PhD students K. Belda, L. He, P. Gebouský and V. Šmídl are well accommodated with us. The undergraduate students J. Andrýsek, J. Kracík, J. Strnad, J. Kratochvílová started to work with us regularly. Drs. H. Gao and P. Ivanova continue their surely successful scientific carriers in US and Bulgaria.

Generally, our Institute deals with analysis and design of systems generating predictions, making decisions or controlling other systems. Our Department deals with the systems that are able to modify their behaviour with the changing environment or operating conditions. This essential ability, called adaptivity, enhances the efficiency of the systems performing the mentioned tasks. During decades of research we have reached significant conceptual, theoretical, algorithmic, software and application results. Our experience is now fructified in ambitious projects like ProDaCTool [100]. The

experience is shared and enhanced further on within the framework of "Research and Education Centre in Adaptive Systems" (RECiAS) [101] coordinated by us.

The interplay between theory and always limited computing power is the key issue we address. We touch it at various levels of generality while solving problems in radiation protection, transportation, management and control of technological systems, nuclear medicine etc. Simultaneously, we improve our know-how in order to widen the applicability of adaptive systems towards complex cases. It is done both by improving the classical adaptive systems and by inspecting new approaches to their construction.

Grants and Projects

The following list acknowledge additional support from many sources that made our achievement possible.

- L. Bakule – *Robust decentralized control of large-scale systems* (GA AV ČR A2075802)
- J. Böhm – *Algorithms and Implementation of Self-tuning Multivariate Controllers* (GA ČR 102/99/1292)
- J. Böhm – *Redundant Parallel Robots and their Control* (GA ČR 101/99/0729)
- H. Gao – *Bayesian Approximate Recursive Identification and On-Line Adaptive Control of Markov Chains with High Order and Large State Space* (GA ČR 102/98/P059)
- T. V. Guy – *Hybrid Self-Tuning Controller* (GA ČR 102/00/P045)
- J. Heřmanská (M. Kárný) – *Influence of Biophysical Factors on Thyroid Cancer Treatment* (IGA MZ ČR, 4581-3)
- L. Jirsa – *Solution of Modelling and Algorithmic Problems of Bayesian Estimation in Nuclear Medicine and Dosimetry of Ionising Radiation* (GA ČR 102/00/D072)

- M. Kárný – *Research and Education Centre in Adaptive Systems: pilot project* (GA ČR 102/99/1564)
- M. Kárný – *Fault Detection and Isolation - Cooperation with Slovenia* (MŠMT ČR ME 245/1998)
- M. Kárný – *ProDaCTool – Decision Support Tool for Complex Industrial Processes Based on Probabilistic Data Clustering* (IST–99–12058)
- F. Kraffer – *Algebro-geometric methods for polynomial matrix operations with applications in control system design* (GA ČR 102/99/D033, suspended by an Individual Marie Curie Fellowship)
- F. Kraffer – *Geometric methods in algebraic theory implementation to multivariable systems* (EC, HPMF-CT-1999-00347, Individual Marie Curie Fellowship)
- P. Pecha – *Customisation of RODOS system for Czech Republic* (SÚJB, contract no. 1042).

University Courses

Education is an integral part of the research. We are supervising a relatively high number of MSc. theses and undergraduate research projects. The interest of students is also attracted by regular ***(under)graduate courses*** we give:

- 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)
- Faculty of Mechanical Engineering, ČVUT
  Tutorials from Mechanics (Dynamics, Statics) (K. Belda)

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, SZTAKI Institute of Hungarian Academy of Sciences and the West Bohemia University.

International Cooperation and Travels

International co-operation was driven by Projects ProDaCTool, GA AV ČR A2075802, MŠMT ČR ME 245/1998, agreements of Academy of Sciences, CEGS and Marie Curie Fellowship. Our major partners are in UK, Ireland, Spain, Slovenia, Sweden, Hungary, Ukraine and France.

International PhD workshop "Cybernetics and Informatics Eurodays: Young Generation Viewpoint" held in Marianska, September 26–30, 2000 was organised by and for students and young researchers. This interdisciplinary workshop helped young people to build new contacts, present their research results and inform their peers on the progress achieved and obstacles met. Contributions of 20 young researchers of 9 nations are accessible at ***www.utia.cas.cz/AS_dept/phd2000.html***. Our students proved to be both active and successful participants as well as organisers. Grants GA ČR 02/99/1564 and MŠMT ME 245/2000 supported them.

Conference trips led to mostly successful presentations:

- L. Bakule, 3rd European Congress of Mathematics, Barcelona, Spain
- . L. Bakule, MATLAB 2000, Prague, [2]
- J. Bůcha, The First Workshop on Ontology Learning, ECAI 2000, Berlin [19]
- J. Böhm, ICARCV 2000, Sixth International Conference on Control, Automation, Robotics and Vision, Singapore, [15]

- K. Belda, MATLAB 2000, Prague, [7]
- T.V. Guy, 8th IFAC Symposium "Computer Aided Control System Design", Salford, UK, [52]
- F. Kraffer, 7th Workshop of Marie Curie Fellows: Research Training in Progress, Paris Observatory, Paris
- N. Khailova, J. Böhm, 4th International Scientific-Technical Conference – Process Control 2000, Kouty nad Desnou – Czech Republic, [106]
- K. Belda, J. Böhm, 4th International Scientific-Technical Conference – Process Control 2000, Kouty nad Desnou – Czech Republic
- P. Pecha, 4-th Int. Conf. on Environmental Impact Assessment, Prague, 11-14 September 2000, [176]
- P. Pecha, Int. Meeting on Nuclear Research and Design Activities, Varna, Bul., 31st May-2nd June 2000, [179]

Long-term stays abroad of our members included:

- L. Bakule, University of Barcelona, Spain, in connection with the project GA AV ČR A2075802
- H. Gao, Mondragon University, Spain, closing a project
- F. Kraffer, Institut de Recherche en Communications et Cybernétique de Nantes, CNRS UMR 6597, Individual Marie Curie Fellowship
- L. Jirsa, Trinity College Dublin, in connection with the project ProDaCTool, IST-99-12058
- P. Ivanova, University of Sunderland, defence of her thesis
- L. Tesař, Trinity College Dublin, in connection with the project Prodactool, IST-99-12058

Short-term stays abroad of our members included:

- K. Belda, Josef Stefan Institute, Ljubljana, Slovenia, in connection with the project MŠMT ME 245/2000
- T. V. Guy, Slovak Technical University, study stay
- T. V. Guy, Ukraine, Gluškov Institute of Cybernetics, Kiev

Polytechnic Institute, study stay
- T. V. Guy, UMIST, Manchester, study stay
- T. V. Guy, Uppsala University, Royal Institute of Technology Stockholm, Linköping University, study stay
- M. Kárný, UK, Reading University, coordination meeting of the project ProDaCTool, IST-99-12058

RESULTS

3.1 ProDaCTool – System Supporting Operators

Complex processes like rolling mill, transportation system, medical diagnostic system etc. offer to the operator a lot of data to be used for an efficient maintenance. Its quality depends heavily on the skills and mood of the operator. Thus, it is desirable to provide him an advisory system. A theoretical and algorithmic basis of such advisory system is under developement (project ProDaCTool IST-1999-12058). It basic idea is simple. Differences in operation quality are believed to manifest themselves in different modes of the distribution of the observed data. This distribution is approximated by a high dimensional mixture of unimodal distributions. Each of them is qualified by the expected performance and the operator is shown univariate cross-sections through the best of them. Applicability is conditioned on ability to perform mixture estimation in high dimensional spaces (say 50 000 records each with 40 variables) [35].

The substantial progress has been made in year 2000. Among others, the decisive problem of initiation of mixture estimation has been solved and factorised version of EM algorithm [105] implemented. Theory gets its expression in software creating MATLAB toolbox Mixtools [163]. Medical

and traffic data extend experimental basis [209] formed by the target rolling-mill data [36]. Adapted techniques for outlier suppression and interpolation of missing or censored data were proposed, see ***www.utia.cas.cz/AS_dept/phd2000.html***. A mixture estimation with mixed continuous and discrete data has been proposed [104]. Promising steps were made in design of optimal quadratic controller for mixture models. It will serve as an advisory tool in so called industrial advisory systems [103].

3.2 Computer-Aided Design of Adaptive Controllers

Testing and polishing. The single-input, single-output version of the computer-aided design of adaptive controllers was extensively tested on laboratory models. They served for verification of the complete design-use cycle. Successful results were obtained with three coupled tanks laboratory model [161]. A ball-and-beam laboratory model was another case successfully tried [102]. Strong nonlinearity caused by a finite length of the beam and by a limited range of inputs calls for a well designed controller that keeps the motion in the desirable domain interior. In the adaptive case, the situation is even more difficult as the adaptation can be spoilt if the controlled process reaches boundaries too frequently. These problems are discussed in [106, 107].

Algorithmic development. Multi-input multi-output version of the computer aided design was addressed by searching for efficient techniques of selecting penalisation weights so that constraints on involved signals are respected. Thesis [164] shows successful results of this development. However, the choice of initial condition for constraint optimization and the computational efficiency are to be improved further on.

Advances in the control design. The LQ controller synthesis was extended to the case when a plant is described by a set of models, representing e.g. different working conditions of a nonlinear plant [15]. This approach can be considered as a contribution to the robustness properties of linear-quadratic (LQ) controllers and it is tightly connected with results reported in connection with ProDaCTool.

Control application in robotics. The possibilities of cooperative control of redundant parallel robot have been tested. Discrete predictive control, inverse dynamics approach and sliding mode control were used respectively [8, 17]. The tests are based on a simulation model of a planar parallel robot that exists also as a laboratory model. During tests algorithms have been modified to be applicable in a control processor connected with the laboratory model.

Object oriented design. New approaches to object oriented design were studied [18].

3.3 Robust Decentralized Control of Large-Scale Systems

A generalized structure of complementary matrices involved in the input-state-output Inclusion Principle for LTI systems including contractibility conditions for static state feedback controllers is well known now [3, 4]. Now, this structure has been extended to contractibility of dynamic controllers in an original way. Necessary and sufficient conditions for contractibility have been proved in terms of both unstructured and block structured complementary matrices for general expansion/contraction transformation matrices. Minimal explicit sufficient conditions for blocks of complementary matrices ensuring contractibility have been proved for general expansion/contraction transformation matrices.

These conditions have been further specialized for particular transformation matrices. All the results have been derived in parallel for three significant cases. In the first case, the control is considered to be selected freely in the initial space. The second case considers the control designed without restriction in the expanded space. This case dominates mainly from the point of view of overlapping decentralized control design. The third case considers a control designed in the expanded space, but within the expansion/contraction scheme known as extension. New existence conditions have been proved for expansion-contraction forms ensuring simultaneuos controllability-observability of both subsystems and overall systems in expansion [5].

Further, the concept of extension has been applied on the decentralized control design of a longitudial headway control of platoons of automotive vehicles with time–varying mass as an uncertain parameter. Simulation results confirmed this approach is convenient methodology for this type of control problems in general [2].

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 in-

ability to compute system-theoretically relevant solutions to various polynomial matrix operations like linear and quadratic equations. Publications [124] and [125] 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 Hybrid adaptive control

Hybrid adaptive hybrid controllers of LQ type complement formerly developed adaptive discrete-time LQG controllers. They rely on recursively estimated controlled autoregressive (ARX) model of the stochastic dynamic system. Often, a long regression vector is needed for a satisfactory modelling. Then, the subsequent LQ design results in an unnecessarily complex and non-robust controller. The proposed hybrid controllers overcome this by modelling inter-sample behaviour using over-sampled data. The resulting model consists of a combination of a convolution modelling of continuous time stochastic controlled system and a piece-wise approximation of input/output signals. The controller synthesis uses approximated values 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. Comparing to the traditional solutions, low order models are sufficient for obtaining a higher control quality. Essentially filters that reflects properties of involved signals [51] are attached to an

LQ controller that care both about controlled signals and their changes.

Wavelet-based modelling Another type of modelling of continuous time system for digital adaptive control has been recently proposed [52]. It employs wavelet-based approximation of the involved noisy signals. Under realistic assumptions, it leads to an ARX model with the regression vector formed by *multiresolution approximations* of the input-output signals. Probabilistic interpretation allows us to use Bayesian approach to structure selection and offers an algorithm for the decision on the structure of multiple models obtained [53].

3.6 Modelling and identification of traffic systems

The problem of heavy car-traffic in large cities became pressing world-wide. We are involved in research counteracting this situation.

Predominantly, we deal with modelling, identification and control of traffic microregions that make building elements of large traffic networks. Measured data are obtained from detectors placed under the surface of the roads near crossroads. They reflect intensities and densities of traffic flow. Timing of signal lights in crossroads are considered as control actions.

A group of students from the Faculty of Transportation Sciences is involved in this long-term research. We guide them and provide them a necessary learning material [162]. Learning-by-doing is the main technique we use. A visible progress has been seen on the following tasks.

Data processing. Systematic processing of multidimensional transportation data from various microregions in Prague has

been performed. Use of static and dynamic models, influence of the model order, forgetting and prior setting have been examined [209].

Simulation of traffic region. Micro-modelling starts with care about each car. The constructed simulator will serve for development and testing of particular algorithms. Logic and tools for programming of microregions were prepared.

Data filtration and traffic prediction. The implemented measuring detectors are often unreliable and improperly placed. Thus data filtration and elimination of superfluous data are necessary. Piece-wise modelling of signals provides the basic filtering tool. Spline approximation of a single variate traffic flow for filtering and prediction is ready for tests on real data. Also, an on-line adaptive filter based on mixture modelling has been constructed for suppression of outliers.

Traffic state estimation. Intensity and density of traffic flow are necessary for a complete description of the traffic state. Simple approximations of their dependencies were looked for. Experiments with parabolic and spline approximation have been performed and they are ready for real-data tests.

3.7 Integration of all Cognitive Functions

We found that our predominantly algorithmic solutions of decision-making problems have to co-operate with knowledge-based approaches. The corresponding knowledge-oriented areas are well developed, however the knowledge creation (machine learning) is mainly oriented on relatively simple systems. Due to our orientation on real applications, our attention focused on machine learning applicable in complex systems. We had continued to address this problem. The basic characteristics of the solution were:

1) The learning problem is solved in a broader context, in a context of a problem solver (PS).
2) PS is integrating all cognitive functions.
3) PS is self-reflective.
4) Knowledge, gained in the areas of artificial intelligence, machine learning, computer science, control engineering etc., is applied to the design of learning itself.
5) Object-oriented technology, computer aided software engineering approaches and tools, Unified Modeling Language, uncertainty and inconsistency processing etc. are used [19, 20].

There is also a backward influence. We applied this solution to problems of object-oriented technology [18].

3.8 Customisation of the RODOS system for ČR

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

Next step towards a practical utilisation of the RODOS system started in 2000 when its latest version was installed at State Office for Nuclear safety. Customisation according to the SONS demands is in progress. RODOS beta version is tested on a new workstation, which is dedicated for a routine utilisation of RODOS.

A profound analysis of the RODOS food-chain module with respect to its use for the Czech territory was done [179]. It includes the new definition of radioecological regions for

the whole country. A special dynamic food-chain model of radionuclides transport were presented in [178]. A collection of data required data each radioecological region of ČR, their pre-processing and integration into RODOS are in progress.

In connection with the RODOS project, methodology and software tools for a partial evaluation of the radiological impact on population – caused by both accidental and routine atmospheric radioactive releases – have been thoroughly examined. Results of comparison analysis between various codes are reviewed in [178]. The compliance of the RODOS design with the governmental regulations fixed in the new Czech Atomic law has been checked.

The generation of the radiological data for purposes of Environmental Impact Assessment analysis is described in [178]. There a spatial distribution of near-ground activity concentrations in air and deposition rates are calculated. The results were submitted for the further EIA evaluation process according to latest US EPA regulations.

3.9 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 the reliable estimation of various quantities met in nuclear medicine, mostly describing the dynamics of accumulation/elimination of ^{131}I. One important stage of the research supported by IGA MZČR has been successfully concluded. It required a solution of various minor but vital problems [1, 231] as well as substantially improved prediction of the absorbed therapeutic dose [77, 78]. Non-traditional ways of accu-

mulation/elimination modelling and improved measurement strategy brought a novel view on some formerly observed discrepancies between diagnostic and therapy evaluations [80]. They significantly contribute to a widely discussed "stunning effect", i.e. hypothesis that the adopted diagnostic techniques influence substantially biological properties of the inspected tissue. At the same time, the results serve directly to practice and they are being implemented in the routinely used software system JOD*NEW*.

Initial retrospective studies performed on clinical data discover dependence of the treatment success on several patient-individual biophysical quantities. The aim is to recommend the optimum values of key optional quantities in order to optimise the treatment result. Here, synergy with the ProDaCTool project has been exploited. Nevertheless, a lot of additional research is foreseen before reaching applicability stage.

The long term research on analysis of dynamic medical image data has continued and further improvements were achieved [201]. The novel algorithm enhances properties of principal component analysis by utilising prior information about the smoothness of biological processes. It significantly enhances the evaluation efficiency of dynamic image studies, especially those with low signal-to-noise ratio.

4 Department of Stochastic Informatics

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Lucie Fialová	–	applied information theory
Jaroslav Franěk	–	information theory
Tomáš Hobza	–	nonparametric density estimation and applications in communication networks
Martina Orsáková	–	regression analysis
Martina Pavlicová	–	spectral theory of random processes

Conferences:

17 lectures, 5 of them invited, have been delivered at international conferences, including

STERMAT'2000, Kraków

1st European Conference on Spatial and Computational Statistics, Ambelside'2000

Workshop on Recent Developments in Regression, Neuchatel

Statistics'2000, Szklarska Poreba

Brussels–Prague Statistics Seminar, Brussel

Controlling Complexity for Strong Stochastic Dependencies, Oberwolfach

Seminar of Norms and Normalization in Disorders of Locomotor Apparatus, Warszawa

Second International Workshop on Independent Component Analysis and Blind Signal Separation, Helsinki

Macromodels'2000, Zakopane

Conférence Internationale sur les Méthodes Mathématiques en Fiabilité, Bordeaux

5th World Congress of the Bernoulli Society, Guanachuato

Grants and Projects:

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

M. Janžura: "Stochastic models of phase transitions in large interacting systems"
(GA ČR, 201/00/1149, 2000 – 2002)

I. Vajda: "Optimization and estimation in communication networks" (GA ČR, 102/99/1137, 1999 – 2001)

J. Á. Víšek: "Sensitivity analysis of robust identification of regression model" (AV ČR, 2075803, 1998– 2000)

International Cooperation

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

- Atlanta, USA (Prof. A. M. Gokhale)
- Amsterdam, The Netherlands (Prof. B. van Es)
- Marburg, Germany (Prof. J. Steinebach)
- Vilnius, Lithuania (Prof. V. Paulauskas, Prof. M. Bloznelis)
- Ilmenau, Germany (Prof. S. Vogel, Prof. E. Liebscher)

- Rostock, Germany (Prof. F. Liese)
- Madrid, Spain (Prof. D. Morales, L. Pardo, M. Menédez)
- Leuven, Belgium (Prof. E. van der Meulen, Prof. A. Beirlant)
- Montpellier, France (Prof. A. Berlinet)
- Baltimore, USA (Prof. J. Smid)
- Budapest, Hungary (Prof. L. Györfi)

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

University Courses

17 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); Probabilisty and Statistics, Probability Theory (M. Janžura); Advanced Parts of Econometrics (P. Lachout); Analysis of Statistical Data (J. Á. Víšek)

Charles University — Faculty of Social Sciences:
Probability and Mathematical Statistics (J. Šindelář).

Czech Technical University — Faculty of Physical and Nuclear Engineering:
Random Procesess (J. Michálek), Information Theory (I. Vajda); 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, fourteen diploma projects and fifteen 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 26 papers have appeared during 2000.

Recent Results

4.1 Estimation of average particle size from vertical projections

A new stereological relationship was derived for the average width of a collection of convex particles in a 3D microstructure. The following steps describe a practical estimation procedure. (i) Select a direction in 3D space called the vertical axis. (ii) Enclose the specimeen containing the collection of particles in a slab of thickness $\triangle$, having parallel faces of area Γ. Orient the slab (our reference space) so that the vertical axis is parallel to slab faces. (iii) Observe the total projection of the reference space along a projection direction that is perpendicular to the vertical axis and uniformly random among projection directions with this property. Identify the vertical axis and the projected images of particles in the projected planar image. It is assumed that the projected images of all particles are observed in the total vertical projection. (iv) On the projected image superimpose a grid containing uniformly spaced cycloids, so that the minor axis (of length a) is perpendicular to the vertical axis. The superimposed grid must have a random position w.r.t. translations in the plane. Calculate the grid parameter β as $\beta = \frac{2naM}{\Gamma}$, where M is the magnification of the projected image and n the number of cycloids in the grid. (v) Count the number of intersections I_C between the cycloids and the boundaries of

the projected images of convex particles. (vi) Repeat step (v) for a number of uniform random projection directions and evaluate the average value $\bar{I}_C$. (vii) Use the total vertical projections in (v) and (vi) to estimate the total number of particles N_0 in the projected image. (viii) Substitute for β, $\bar{I}_C$ and N_0 in the new stereological equation $\bar{D} = \frac{\bar{I}_C}{2N_0\beta}$, to estimate unbiasedly the average width of particles.

The result is applicable to any arbitrary collection of convex particles, the particle orientations need not be isotropic. Only intersection counts are required, it is not necessary to measure sizes of the particles in the projected images.

4.2 Estimation and smoothing of instantaneous frequency of noisy narrow-band signals

The need to estimate the parameters of a nonstationary tone in additive white Gaussian noise arises in many engineering applications. As representatives let us mention radar processing or estimating the velocity of a fluid by processing laser velocimetry data. Often, the data is highly nonstationary in that not only does frequency vary in time, but the signal-to-noise ratio (SNR) does as well. We studied estimating instantaneous phase and frequency of such nonstationary signal using a recently proposed algorithm called Multiple Frequency Tracker (MFT). We proved asymptotic equivalence of MFT with the Kalman filter (in the linear filter approximation).The derived results include guidelines for the design variables of MFT, as they take into account initial uncertainty of the frequency and phase.

Next, we derived the backward smoothing filter for estimating the instantaneous frequencies off line, and we showed

that the smoothing variant of the algorithm gives estimates with a mean square estimation error which is about one quarter of the variance of tracking procedures.

4.3 Research of random point processes with increments

The process of random sums driven by counting processes (compound, cumulative processes) were studied. A general nonparametric regression model was considered both for the intensity of counting process and for the distribution of increments. The method of nonparametric regression was adapted for the estimation of moments (the mean and the variance) of increments. The random estimation of moments (the mean and the variance) of increments. The random effect model was used for the analysis of heterogeneity of a set of processes. Further, a method of prediction of future behaviour of the process was proposed, on the basis of random sampling. The procedures were used for the modelling the process of increasing damage in the field of reliability analysis, and for the analysis of heterogeneity of financial processes.

5 Department of Econometrics

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General:

A staff of the Department has been interesting in theoretical economics and generalized decision making procedures, and theoretical econometrics. Fuzzy approach has been using to theoretical framework for decision making. Main research fields are in the following areas:

- Stochastic economics, and econometrics, and econometric modelling,
- theoretical fuzzy set approach to decision making,
- stochastic differential – difference equations and its application to the mathematical finance,
- stochastic optimization,
- uncertainty processing in expert systems.

Grants and Project:

- 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 ČR No. A 1075905)
- K. Sladký: *Dynamic Models under Uncertainty in Economics and Finance* (Grant GA ČR No. 402/99/1136)
- M. Vošvrda: *Rate of Assets Returns Dynamics. Application for the Czech Republic* (Grant GA ČR No. 402/00/0439)

University Courses:

- *University of Economics, Prague:*
  - J. Kodera - Capital Markets
- *Charles University, Faculty of Social Sciences :*
  - A. Derviz - International Finance
  - V. Kaňková - Decision in Economics - Deterministic and Stochastic Optimization
  - M. Mareš - Game – like Behaviour in Economic Situation
  - K. Sladký - Stochastic Processes with Economic Applications
  - M. Vošvrda - Theory of Probability and Statistics

  - M. Vošvrda - Theory of Economic Cycles (SOKRATES)
  - M. Vošvrda - Theory of Capital Markets
  - M. Vošvrda - Analysis of Derivatives

- *Czech Technical University, Faculty of Electrical Engineering:*
  - M. Mareš - Coalitional Games Theory

Guests and visitors:

- Prof. Kurt Marti (Universität der Bundeswehr München, Germany)
- Prof. Etsujiro Shimemura (Japan Advanced Institute of Science and Technology, Japan)
- Prof. Dr. Peter Flaschel (Dept. of Economics, University of Bielefeld, Germany)

Diploma and Doctoral projects

Diploma

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

Doctoral

- Charles University, Faculty of Mathematics and Physics (supervisor V. Kaňková - 1, K. Sladký - 2)

- Charles University, Faculty of Social Sciences (supervisor M. Vošvrda - 3)

Conferences Participation

1. Fuzzy Set Theory and Applications 2000. Liptovský Ján (Slovak Republic), February 2000 (Komorníková, Mareš, Mesiar, Novák)

2. Topical Issues in Central Banking. London, March 2000 (Derviz)

3. Information Processing and Management of Uncertainty 2000. Madrid, May 2000 (Mesiar, Mareš)

4. 7th Vienesse Workshop on Optimal Control, Dynamic Games and Nonlinear Dynamics. Vienna, May 2000 (Sladký, Vošvrda)

5. International Conference on Partial Knowledge and Uncertainty. Rome, May 2000 (Mesiar)

6. PRASTAN 2000. Bezovec (Slovak Republic), May 2000 (Komorníková, Mareš)

7. World Automation Congress. Wailea, Maui (Hawaii), June 2000 (Novák)

8. 20th Linz Seminar on Fuzzy Sets. Linz (Austria), June 2000 (Mesiar)

9. EURO XVII. Budapest, July 2000 (Kaňková, Sladký)

10. Euro Symposium on Computational Intelligence. Košice (Slovak Republic), August 2000 (Mesiar)

11. Operations Research 2000. Dresden, September 2000 (Kaňková, Sladký)

12. Mathematical Methods in Economics 2000. Prague, September 2000 (Kaňková, Sladký, Vošvrda)

13. 11th ECMI Conference. Torre Normanna, Palermo (Italy), September 2000 (Novák)

14. International Data Processing 2000. Innsbruck (Austria), September 2000 (Mareš)

15. ALGORITHMS 20000 (15th Conference on Scientific Computing). Podbanské (Slovak Republic), September 2000 (Komorníková)

16. 16th Summer School on Real Functions Theory. Liptovský Ján (Slovak Republic), September 2000 (Mesiar)

17. IX. CARTEMI. Grado (Italy), September 2000 (Mesiar)

18. SOFSEM 2000. Milovy (Czech Republic), November 2000 (Novák)

19. Fall Econometric Day, Prague, December 2000 (Kaňková, Kodera, Sladký, Vošvrda)

20. Quantitative Methods in Economics. Stará Lesná (Slovak Republic), November 2000 (Kaňková, Sladký, Vošvrda)

21. IISA. New Delhi (Indie), December 2000 (Kodera)

22. APIEMS. Hong Kong, December 2000 (Kodera)

International Cooperations

Members of the Department participated in joint research with their collegues from University of Amsterdam (Department of Economic Sciences and Econometrics), JAIST (Japan), University of Gent (Belgium), University of California at Berkeley, JKU Linz, University Alcata de Henares, University of Novi Sad, University La Sapienza Rome, University of Paris 6, University of Salermo and Artificial Intelligence Research Institute IIIA – CSIC, Bellaterra, Barcelona.

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

Public Utility Services

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

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

M. Mareš is chairman of Czech association for the Club of Rome, Treasurer of the Czech Society for Cybernetics and Informatics and member of the American Mathematical Society, member of the European Society for Fuzzy Logic and Technologies, Editor-in-chief of journal Kybernetika, member of Boards of the research programmes INFRA 2 and Support of Research on the 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 Republic.

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

R. Mesiar is member of Editorial Board of the International Journal Fuzzy Sets and Systems.

Results

5.1 Economic Dynamics

A central question of the investment policy is whether the foreign investments change qualitative properties of a dynamical economic system as a system of the first order nonlinear differential equations with feedback function controlled by a capital/output ratio parameter. An economic system without the foreign investments has been analyzed by an equation of the Lienard type. The economic system with the foreign investments has been analyzing by the Hopf bifurcation as well [228].

5.2 Macroeconomic Modelling

A macroeconomic model of the Czech Republic consists of 20 equations and it describes both the real and the monetary side of the Czech economy. The model is based on a model that was constructed earlier. The main difference between this new model and its previous version is the length of one period. The previous version used yearly data, but the final results were not quite stable. In the new model, the length of one period is one quarter and the data are counted from moving sums and form moving averages. This approach to the data prevents the model from problems of seasonal effects. The data used for this model have already

been collected. It have also been created the procedure that helps to find relationships by means of a linear regression. Now, it has been doing searching for these economic relationships. The complete results of the model should be known in the near future. First version was published as UTIA's Research Report.[134]

5.3 Theoretical Finance

5.3.1 Uncertainty Principle

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 capital 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. Correct estimation and prediction of the volatility is thus most important for major finantial institutes, because the volatility is directly related to usual risk measures [226], [227].

5.3.2 Sources of Exchange Rate Volatility in a Decentralized Bayesian Multi-dealer Foreign Exchange Market

A model of dynamic optimization in continuous time under diffusion uncertainty for an international investor with the Forex dealership function, is constructed. The dealer operates in a partially decentralized multiple dealership market, and is imperfectly informed about the economic fundamentals. He uses a Kalman-Bucy filtering procedure to update

beliefs about the national asset returns and the aggregate cross-border order flow. As a result, one can explain the observed excessive volatility of the freely floating exchange rates by the Bayesian learning effects. This result offers a monetary authority a recipe for evaluation of an intervention or another major event in the Forex market [32].

5.4 Cooperation Model With Vague Expectations

The research oriented to realistic model of cooperation, which was realized in the previous years, has continued also in 2000. Its basic concepts follow from the theory of coalitional games as a fundamental mathematical representation of cooperative situations. In the real negotiations which are realized before the proper realization of the game, the pay-offs can be only subjectively expected. This subjectivity is to be included into the processed cooperation model and the mathematical tool adequate to its structure is the fuzzy set and fuzzy quantities theory [142].

The theory of coalitional games distinguishes two main types of coalitional games, those ones with and without transferable utility. The possible pay-offs in each of them are represented by different mathematical tools – for games with transferable utilities by real numbers, for games with non-transferable utility by sets of real-valued vectors. It means that each of these types is fuzzified by means of different fuzzy concepts - by fuzzy quantities and by fuzzy subsets of a vector space, respectively. The comparison of their properties, started in 1999, has continued also in the referred year. The results, showing that the fuzzification of games with non-transferable utility displays slightly weaker relations between the deterministic and fuzzy coalitional games, were accepted for publication in "International Journal on

Uncertainty, Fuzziness and Knowledge-Based Systems".

Further topic related to the fuzzy coalitional game theory and studied in 2000 was the existence and properties of an analogy to the deterministic solution called Shapley value of coalitional game with transferable utility. For the fuzzy coalitional games with transferable utility an analogy of Shapley formula was derived in 2000. It deals with fuzzy quantities instead of crisp real numbers. It was shown that the vector of fuzzy Shapley values computed by the modified formula fulfills a set of axioms which are analogous to those ones formulated in the deterministic case [143].

The research of fuzzy Shapley value has concluded the study of the fundamental properties of fuzzy coalitional games. The achieved results were summarized in a monography "Fuzzy Coalitional Games – Cooperation With Vague Expectations" which is accepted for publication by Physica-Verlag (Heidelberg).

5.5 Mean Variance Models in Markovian Decision Processes

Mean variance models in Markovian decision processes were analyzed. In particular, a discrete time Markov reward process with finite state and action spaces are considered. In contrast to the classical models, it is assumed that instead of maximizing the long run average expected return (i.e. the mean reward per transition) the long run mean variance is minimized, i.e. either the ratio of the long run variance of the total reward to the long run total reward or the ratio of the long run variance of the total reward to the square of the long run total reward. It can be shown that the long run mean variance can be considered as the difference of the ratio of the (long run) second to first moments of total expected rewards and the long run average return. In particular, our

attention is focused on the (weighted) difference of the ratio of the long run second to the long run first moments of total expected rewards and the long run average return. The long run expected return and the long run mean variance are then special cases of the considered weighted difference criterion.

Mean variance models are particularly important for evaluating the portfolio outcome. An algorithmic procedure is suggested for finding Pareto optimal policies for the considered (weighted) mean variance and square mean variance optimality criteria. Our approach heavily employs ideas for finding optimal long-run average return of Markov and semi-Markov decision processes [199], [198], [200].

5.6 Stochastic Programming and Decision in Economy

Main attention was paid (in the year 2000) to multistage (one criterion) stochastic programming problems with individual probability constrains. In particular, some stability results and exponentional rate of the convergence of empirical estimates were introduced and proven for this type of the multistage problems; see e.g. [96]. To achieve these results some special type of the Markov dependence (satisfied in many applications) was assumed.

However, since it is reasonable rather often to evaluate an economic activity simultaneously by several real-valued functions multiobjective stochastic programming problems were also investigated. In details, one stage multicriteria stochastic programming problems with individual probability constrains were investigated (see e.g. [98] [99]) and, moreover, some already well–known results on the stability and the empirical estimates for one criterion stochastic programming problems were generalized to the this multicriterion case.

6 Department of Pattern Recognition

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Secretary:

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Petr Somol	–	Statistical Pattern Recognition e-mail: somol@utia.cas.cz

Postgraduate Students:

Pavel Žid	–	Image Segmentation
Vojtěch Havlíček	–	Texture Synthesis

Pavel Paclík	–	Statistical Pattern Recognition
Aleš Malík	–	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 (cooperation with the Faculty of Management, University of Economics Prague); No. VS96063
- M. Haindl, "Texture Modelling"
  Grant Agency of the Czech Republic; No. 102/00/0030
- M. Haindl, "Computer Aided Quantitative Fractography of Fatigue Failures"
  Grant Agency of the Czech Republic; No. 106/00/1715

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

- Faculty of Electrical Engineering, Czech Technical University, Prague
  A. Malík: "Model Selection for Finite Mixtures in Statistical Pattern Recognition"
  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 health care management"
  P. Pudil: "Applied artificial intelligence for management"

- Faculty of Transportation Sciences, Czech Technical University
  J. Novovičová: "Probability Theory"
  J. Novovičová: "Mathematical Statistics"
  J. Novovičová: "Advances in Statistics" (for doctoral study)

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, P. Somol — University Surrey, GB; University of Valencia, Spain, University of Hokkaido (joint research project), University of Salzburg (joint research project)
  P. Pudil, J. Novovičová — University of Cambridge, GB
  P. Paclík — Delft University of Technology, The Netherlands
  J. Novovičová — Centro di Investigacion en Computation - IPN, Mexico D.F., Mexico

- Co-operation on image data modeling:
  M. Haindl — University Surrey, GB; University of Auckland, New Zealand
  P. Paclík — Delft University of Technology, The Netherlands

- CPR Workshop 2000, Peršlák, Czech Republic, February 2000 ([55])
- 8th International Conference in Central Europe on Computer Graphics, Visualization and Interactive Digital Media, Plzeň, Czech Republic, February 2000 ([62])
- 4th World Multiconference on Systemics, Cybernetics and Informatics, Orlando, USA, July 2000 ([206],[59], [149])
- Joint IAPR International Workshops SSPR 2000 and SPR 2000, Alicante, Spain, August 2000 ([60],[150], [129])
- 15th IAPR International Conference on Pattern Recognition, Barcelona, Spain, September 2000 ([56],[61], [57], [205])
- 5th World Congress of the Bernoulli Society for Mathematical Statistics and Probability, and 63th Annual Meeting of the Institute of Mathematical Statistics, Guanajuato, Mexico, May 2000.
- 6th Annual Conference of the Advances School for Computing and Imaging (ASCI), Lommel, Belgium, 2000 [173]
- Second ICSC Symposium on Neural Computation, Berlin, Germany, May 2000, [50]

Research Scope

- Statistical Pattern Recognition
- Random Field Modelling
- Probabilistic Neural Networks
- Expert Systems
- Virtual Reality

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

A robust and general method for the recognition of traffic devices like road signs in traffic scene images is necessary for the creation of a Driver Support System. Colour may be used as a useful attribute for the decomposition of classification problem into several apriori defined road sign

groups/subproblems. The colour free developed method for the road sign classification allows the same problem decomposition as its colour-based counterpart. The methods may be used in combination with the colour-independent sign detection algorithms. The road sign recognition system then works entirely without colour which may be used as an alternative procedure when the input traffic scene images lacks good colour information.([173])

Driver support systems of intelligent vehicles will predict potentially dangerous situations in heavy traffic, help with navigation and vehicle guidance and interact with a human driver. Important information necessary for traffic situation understanding is presented by road signs. A new kernel rule has been developed for road sign classification using Laplace probability density. Smoothing parameters of the Laplace kernel are optimized by the pseudo-likelihood cross-validation method. To maximize the pseudo-likelihood function, an Expectation-Maximization algorithm is used. The algorithm has been tested on data set with more than 4900 noisy images. A comparison to the other classification methods has been also made. [174]

Two new methods of adaptive floating search for feature selection have been developed. 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 user s setting of certain parameters.

A new sub-optimal subset search method for feature selection was introduced. As opposed to other till now known subset selection methods the oscillating search [205], [204] is not dependent on pre-specified direction of search (for-

ward or backward). The generality of oscillating search concept allowed us to define several different algorithms suitable for different purposes. We can specify the need to obtain good results in very short time, or let the algorithm search more thoroughly to obtain near-optimum results. In many cases the oscillating search over-performs all the comparable methods. The oscillating search may be restricted by a preset time-limit, what makes it usable in real-time systems.

A simple modification of the classical Branch & Bound algorithm has been defined and tested to save computational time. [203] Its definition served as a base for further research, as described in the following.

Based on detailed study of the Branch & Bound algorithm principle we introduced a novel algorithm for optimal subset selection called "Fast Branch & Bound" [206]. Due to its mechanism for predicting criterion values the algorithm finds optimum usually several times faster than any other known Branch & Bound algorithm. This behaviour is expected when the algorithm is used in conjunction with non-recursive and/or computationally expensive criterion functions. The algorithm has been recognized to be an important addition to the feature selection framework. Moreover, it may be used for different problems of subset selection as well.

Different approaches to feature selection were tested and compared in cooperation with universities in Salzburg and Sapporo. Properties, performance and overall usability of statistical and genetic approaches to feature selection have been described in [149], [150], [129].

6.2 Probabilistic Neural Networks

The self-organizing map (SOM) algorithm of Kohonen for training of artificial neural networks has been shown to be closely related to a sequential modification of EM algorithm for maximum-likelihood estimation of finite mixtures [46]. The established correspondence provides a helpful theoretical basis for interpretation of the properties of SOM algorithm and for the choice of involved parameters.

The well known "beauty defect" of probabilistic neural networks is the biologically unnatural complete interconnection of neurons with all input variables. It has been shown that this undesirable property can be removed by a special subspace approach without leaving the exact framework of Bayesian decision-making. As demonstrated in a recent paper the related structural optimization based on EM algorithm is controlled by an information criterion. The method has been applied to recognize unconstrained handwritten numerals from the database of Concordia University, Montreal, Canada. The obtained recognition accuracy is comparable with the previously published results though it has been achieved without any preceding feature extraction [50].

The multiple classifier fusion has been proposed as a natural way to improve the recognition accuracy of the probabilistic neural networks. Instead of combining different a posteriori probabilities, we make a parallel use of the output vectors to compute the standard Bayesian classifier again. The complete design methodology based on EM algorithm has been applied to recognize unconstrained handwritten numerals from the database of Concordia University, Montreal [47].

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. Several Markov random field and 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 natural colour texture modelling [60], [59], image restoration [55], [56] and in automatic acquisition of virtual reality models [62], [61] applications.

We have proposed a novel recursive square-root filter based procedure for efficient estimation of the least square or the maximum pseudo-likelihood type of statistics [57], [58]. The first known recursive Gaussian Markov random field pseudolikelihood parameter estimator was derived from these results. Two original image restoration algorithms using a combination of causal and non-causal weak Markov models were introduced in [55], [56]. Both methods are fully adaptive, numerically robust but still with moderate computation complexity. Their restoration quality is comparable with the best current image restoration methods while being much faster. Multiresolution approximations of non-causal Gaussian Markov and causal weak Markov colour texture models together with their parameter estimation and synthesis were proposed in [59], [60]. Both models enable to describe complex spatial relations due to independent Markov submodels for single spectral and frequency factors.

7 Department of Image Processing

Head of Department:

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Visitor:

Jaroslav Kautský	–	Flinders University, Adelaide, Australia

Grants and Projects:

- 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)
- J. Flusser - Image fusion methods for degraded and incomplete data (Grant Agency of the Czech Republic, No. 102/00/1711 – jointly with the Astronomical Institute, Academy of Sciences of the Czech Republic)

- 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)

University Courses:

Jan Flusser	–	"Digital Image Processing" at the Faculty of Mathematics and Physics, Charles University, Prague.
Jan Flusser and Barbara Zitová	–	"Image Processing and Pattern Recognition", at the 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.
Lubomír Soukup	–	"Adjustment of Geodetic Networks" at the Faculty of Civil Engineering, CTU, Prague.

The research activity is focused on the following areas:

- Theory of the invariants
- Recognition of distorted images and patterns
- Image fusion
- Image restoration
- Applications in remote sensing, astronomy, medicine, agriculture, geodesy and geophysics

7.1 Camera Motion Estimation from Defocused Images

To estimate a current position of an uncalibrated moving camera with respect to its previous position is a frequent task in computer vision. Information which is available consists of images taken at the initial and current positions of the camera. Provided the images have at least partial overlap (the task is not solvable otherwise), an accurate estimation of the parameters of the spatial transformation between the images is the key to solving this problem.

There are basically two different approaches to the estimation of transform parameters: correspondence-based and correspondenceless ones. In the correspondence-based approach, any method of image-to-image registration can be employed to find corresponding control points and to estimate the parameters of the transform model via interpolation or least-square fit. Correspondenceless methods look at the images globally (they require a complete overlap) and try to find the transform parameters directly (phase correlation, image normalization).

We concentrated ourselves to the estimation the moving camera position in the situation when one of the images is

blurred in an unknown manner. The blur can be introduced by various factors such as wrong focus (caused by 3-D nature of the scene, camera motion along optical axis or zooming), atmospheric turbulence (important particularly in remote sensing and astronomy), diffraction and camera vibration, among others. We assume the blur, regardless of its particular type, can be modeled as a convolution of the original image with an unknown point-spread function of the imaging system.

The proposed motion estimation method is based on the image registration by means of control points (CP's). Since at least one of the images is supposed to be blurred, a new registration technique, which is insensitive both to the type and amount of blurring and does not require any deblurring/restoration of the images, is presented. First, CP candidates are detected in both initial and current frames. Matching of the CP candidates is performed in the space of invariant signatures called *combined invariants*, based on complex moments of the image function. They are calculated over a neighborhood of each CP candidate. As soon as the matched CP pairs are found, the parameters of the image-to-image transform are calculated and, finally, the new camera position is estimated. Since the registration is based on local properties of images, a partial overlap of the frames is sufficient. Detailed description of the method can be found in [232].

This work has been supported by the grant No. 102/00/1711 of the Grant Agency of the Czech Republic.

7.2 Multimodality Data Registration Techniques

The task of registration of unimodality data, i.e. data acquired with a same measuring device, has undergone a close investigation during the last two decades with many satisfactory results (see, for instance, our recent paper [41]). Therefore the focus of research has shifted in the recent years toward a more challenging task of multimodality registration. Data of different modality are obtained either by measuring the given scene with different devices or by measuring a time-evolving scene. A typical example of multimodality data is the triplet CT, MR, and PET medical volume images of patients where it is often necessary to align images so that complementary information from these modalities can be utilized simultaneously to improve diagnosis and treatments. Other examples are Digital Subtraction Angiography during which a sequence of CT images is taken to show the passage of injected contrast material through vessels, and breast MRI for detection of cancer. In both of the tasks the dynamic sequence of CT or MR scans is acquired after the injection of contrast media and due to the patient movement the scans have to be first registered before any further processing can be conducted. In the search for multimodality data we do not have to go so far every RGB image may be regarded as a three-modality data. Although the registration task is often trivial in this case.

Classical similarity measures proposed for unimodality registration, like cross correlation (CC) or moment invariant, are based solely on image intensity values. Such measures are inadequate for multimodality data for obvious reasons and thus new similarity measures based on image histograms and image gradients were suggested. The leading position

probably belongs to the mutual information (MI) that is based on the joint probability of intensities of corresponding pixels in two images. Typically, the joint probability is estimated via Parzen windows and histograms. The strength of MI-based registration is in its ability to discard intensity patterns in different modalities that are not relevant to registration. The drawbacks encountered in the CC-based techniques are even underlined here, the necessity to search the space of transformation parameters is extremely time consuming with the thread of ending in a local minimum. The powerful tool of phase correlation may bring some benefits but the behavior of this technique in the multimodality framework is still under investigation.

This work has been supported by the grant No. 102/00/1711 of the Grant Agency of the Czech Republic.

7.3 New YHS Color Coordinate System

In digital images, color can be described by its red (R), green (G) and blue (B) coordinates (the well-known RGB system), or by some its linear transformation as XYZ, CMY, YUV, YIQ, and/or others. Nevertheless, sometimes it is useful to describe the colors in an image by some type of cylindrical-like coordinate system, it means by its hue, saturation and some value representing brightness. If the RGB coordinates are in the interval from 0 to 1, each color can be represented by the point in the cube in the RGB space. Let us imagine the attitude of the cube, where the body diagonal linking "black" vertex and "white" vertex is vertical. Then the height of each point in the cube corresponds to the brightness of the color, the angle or azimuth corresponds to the hue and the relative distance from the vertical diagonal

corresponds to the saturation of the color.

Our goal is to find a color space, which would be suitable for computations in the color cube, such as color specification, coordinate transformation, color manipulation or coding of multiparameter distributions into integrated displays. It should satisfy some demands as:

1. The brightness should be linear combination of all three RGB components. At least, it should be continuous growing function of all of them.

2. The hue differences between the basic colors (red, green and blue) should be 120° and similarly between the complement colors (yellow, purple and cyan). The hue difference between a basic color and an adjacent complement one (e.g. red and yellow) should be 60°.

3. The saturation should be 1 for colors on the surface of the RGB color cube, it means in case of one of the RGB components is 0 or 1 except black and white vertices and it should be 0 in case of R=G=B.

Our approach is following:
The brightness as general linear combination of RGB

$$Y = w_R R + w_G G + w_B B, \tag{1}$$

where $w_R, w_G, w_B > 0$ and $w_R + w_G + w_B = 1$. The usual choice is $w_R = 0.299$, $w_G = 0.587$ and $w_B = 0.114$.

The hue as exact angle in the color cube

$$H = \tan^{-1}\left(\frac{\sqrt{3}(G-B)}{2R-G-B}\right). \tag{2}$$

It is supposed in the range from 0 to 360° according to the signs of the numerator and the denominator.

The saturation

$$S = \max\left\{\frac{Y-R}{Y}, \frac{R-Y}{1-Y}, \frac{Y-G}{Y}, \frac{G-Y}{1-Y}, \frac{Y-B}{Y}, \frac{B-Y}{1-Y}\right\}. \tag{3}$$

If $Y = 0$ or $Y = 1$ then $S = 0$.

The new YHS color coordinate system has some advantages in comparison with the existing systems. The brightness Y is the gray level version of the image, it depends on all three RGB components linearly. The coordinate system is centered, there are regular distances between the hues of the basic colors. The saturation uses full range from 0 to 1 for all values of the hue and the brightness. The full description including back conversion from YHS to RGB and comparison with existing systems can be found in [214].

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Grants and Projects

- J. Kadlec – *Centre of Applied Cybernetics* (LN00B096 The Ministry of education of the Czech Republic,2000-2004)
- J. Kadlec (J. Schier) – *High Speed Logarithmic Unit* (ESPRIT 33544 Long Term Research, 1999-2001)
- J. Kadlec (M. Kadlecová) – *"IDEALIST-EAST" Information Dissemination and European Awareness Launch for the IT Programme in East Europe* (CP97-7122 1998-2000)
- M. Kadlecová – *"IDEALIST-5FP" Information Dissemination and European Awareness Launch for the IST Programme under the 5-th Framework Programme* (No. IST-1999-14184, 2000-2003)
- 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 – A High Speed Logarithmic Arithmetic Unit (OK314, The Min. of educ. of the Czech Republic,1998-2000)
- J. Kadlec – Decision-Support Tool for Complex Industrial Processes based on Probabilistic Data Clustering (OK317 The Min. of educ. of the Czech Republic, 1998-2000).
- J. Kadlec – Information Dissemination and European Awareness Launch for the IT Programme in East Europe (OK346 The Min. of educ. of the Czech Republic, 1998 - 2000).
- J. Kadlec – *Expert for the IST programme* (The Ministry of education of the Czech Republic, 1999-2004)

University Courses

The members of the DSP group give these selective post-graduate courses:

- Faculty of Electronic Engineering, Czech Technical University

Adaptive methods for signal processing (J. Kadlec)
Parallel algorithms and architectures (J. Kadlec)

Conferences, Workshops and Seminars

We have organized or co-organised several conferences related to EU projects in the area of IST (Information Society Technology):

- IST Information Day to the 3rd IST Call. 8. 3. 00,

Prague; 80 participants. Key speakers: Dr. Habers (EU), Dr. Kadlec (NCP ID-EA CZ), Ing. Hillerova (NCP IST CZ), Dr. Hayer (IT Prize), Mgr. Cerna (UNIS, Ltd.), Dr. Hulova (OR-CZ, Ltd.). Co-organised with the project FEMIRC CZ.

- One day seminar about European Integration, 5FP and Idealist-east at 6th International Conference " Information Systems for Agriculture and Forestry", SEC 2000, 22. - 24. 2. 00, Sec u Chrudimi (presented by Dr. Kadlec), 27 participants. Organised by Help Service Education, Ltd. and Forest management Institute, Prague.
- NINET - workshop, Technological Centre in Prague, 10. 5. 00. Organised by FEMIRC CZ, 40 participants. 4-hour seminar about 5. FP and IST WP (presented by Dr. Kadlec).
- "Successful Proposal Writing" 1 day workshop, UTIA Prague, 26. 6. 00. Repeated 18. 9. 00 Key speaker Dr. Drath, Singleimage. 21 participants and 25 participants.
- Contacts '99, 16. 2. 00, UTIA, one day meeting with the company Schlunberger, Fance and six CZ companies about future co-operation. Co-organised with FEMIRC CZ.
- One day workshop for CZ co-ordinators of not-retained proposals in the 1st IST Call, UTIA, Prague, 25. 2. 00, 6 participants. Organised by Dr. Kadlec and Dr. Stecha (IST expert).
- Preparation of the CZ Stand at the New Associated States section of the Exhibition IST'00 Nice, France, 3.11-6.11.2000. A joint activity with the Technology Centre, AS CZ and the Czech Ministry of Education.

Guests

- *Dr. Albu* UCD Dublin Ireland, 1 week, Esprit project 33544 (fast projection algorithms)

- *Dr. A Benshop* Phillips Research Endhoven, Holland, Esprit project 33544.
- *Dr. E Chester*, University of Newcastle, UK, Esprit project 33544.
- *Dr. Drath*, Singleimage, Ltd., UK, IDEALIST-EAST project.
- *Students ISEP* 3-week stay of 3 students from ISEP, Paris, France.
- *Ondračka, Oravec* 2 short stays of students from STU Bratislava, SK. (research related to the MS diploma work)
- *Dr. Sviežený* ISEP Paris, France, cooperation in DSP research.
- *Dr. B. Mikovičová* ISEP Paris, France, 2 weeks, Rapid prototyping of DSP algorithms from SIMULINK to IDA board (Texas Instruments TMS320C31)

Travel and International Cooperation

Our travel was related mainly to coordination and working visits related to EU projects:

- J. Kadlec:

EU Brussels BE. Consultations and preparations of an IST project SOCED (IST, KA IV, E6 unit Dr. P. Van Hove).
Philips Research Eindhoven, Holland, DSP workshop, preparation of IST FET project.
University of Newcastle, UK. Defence of the first year results of Esprit project 33544 HSLA.
UCD Dublin Ireland. Joint research (normalised LATTICE algorithms) for Esprit project 33544 HSLA 15.11-20.11. 2000.
CZ-D partnering day. FZI Karlsruhe, Germany. 26.-29.9.2000.

Evaluation of EU projects, Brussels, 4.6-9.6.2000.
Coordination meeting of the project IDEALIST-FP5 DLR, Koln, Germany, 9.12-12.12.2000.
IST Committee as CZ representative Brussels, BE, 26.1; 18.2; 9.3; 22.3; 13-14.4; 11.5; 20-21.6.; 12-13.7; 26-27.7.; 11/12.9; 20-21.9.; 18.10.; 6.12.2000.
Preparation of the CZ Stand at the New Associated States section of the Exhibition IST'00 Nice, France 3.11-6.11.2000
Exhibition stand and computer demonstrations of Logarithmic ALU IP-core at FPL2000, (10th International Conference on Field Programmable Logic and Applications), Villach, Austria 27-30.8.2000.

- J. Schier:
  Philips Research Eindhoven, Holland, DSP workshop, preparation of IST FET project.
  QUB Belfast, Northern Ireland, Preparation of an IST FET project
- A.Heřmánek:
  ESAT SISTA, KUL Leuven. 10 day working visit and joint research with Prof. Marc Moonen in the area of subspace methods.
  FPL2000, Villach, Austria 27-30.8.2000.
- M. Tichý:
  Euro-Par 2000, European Conference on Parallel Computing, Munich, Germany, 29.8-1.9. 2000.
  ESAT SISTA, KUL Leuven.5 day working visit, parallel processing.
- R. Matoušek:
  ICSS conference, Geneve,(CH), 27.5-1.6.2000.
  FPL2000, Villach, Austria 27-30.8.2000.
- M. Líčko
  FPL2000, Villach, Austria 27-30.8.2000.

- A. Rektorová:
CZ-D partnering day. FZI Karlsruhe, Germany. 26.-29.9.2000.

RESULTS

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.

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.

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. This includes the development of low-level drivers for advanced PCI peripheral devices.

Majority of our implementations is oriented towards creation of advanced software tool-boxes and packages, connected to advanced embedded digital signal processing hardware or field programmable gate arrays. Examples:

- A 32-bit Logarithmic Arithmetical unit has been designed in the form compatible with the new hardware design flow DK1 of the UK based company Celoxica.

  `http://www.celoxica.com/programs/university/academic_papers.htm`

- The corresponding libraries are tested by the research establishment DERA Malvern, UK (DSP and radar applications).

- We are currently in the exploratory stage of the possible closer cooperation with the ESA (European Space Agency) Holland in the area of the design of the next generation of re-configurable controllers for EU space applications).

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".

This helps not only to the companies. It helps to build links between research and potential users. It helps us to specify, what might be needed as the outcome of our work.

8.1 32bit Logarithmic Arithmetic Unit in FPGA

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 [27], [208].

This approach leads to a solution, which is suitable to VLSI and FPGA implementation.

We have achieved hardware implementation of the complete logarithmic ALU, operating with the clock frequency 52 MHz on the XILINX VirtexE FPGA device. The latency of the ALU is 9 to 12 clock cycles for ADD and SUB and just 2 cycles for all other operations. The complete ALU takes just 7 percent of the internal logical resources of the XCV2000E circuit and 4 external SRAM memories are interfaces [76].

As far as we know, it is the first complete and published solution of the arithmetic IP core which has the precision

and data range comparable or outperforming the IEEE 32 bit floating point standard which is suitable for the use in the FPGA designs. Advanced algorithms from the area of control and digital signal processing can be implemented in the FPGAs now.

We have implemented and verified complete 32 bit processor LEON-II. The VHDL processor design has been offered to the research from the European Space agency in the spring 2000. This RISC (reduction instruction set) processor is compatible with the open specification of the SUN SPARC-8 architecture. The assembler and the GNU C compiler and GDB debugger support the implementation. This result has open the possibility to construct and implement dedicated systems on chip which can have special combination of hardware peripheral devices on one FPGA circuit.

This result pushed forward the level of the presently mastered engineering design capabilities in the Czech Republic into qualitatively new area.

8.2 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 [170],[64], [146].

Our research has been focussed on development of software supporting the Real-Time Workshop (Matlab 6), 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.

Research resulted in support for:

- 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 [138].
- 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 [192].

8.3 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.

8.4 Support for Czech Participation in EU Research Programmes

The publication "Czech Republic - Information Society Technologies - Contacts 2000" was extended and published as a multimedia CD ROM in the co-operation with FEMIRC CZ.

The partner-search data from the CD 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/

This directory has been advertised at the central EU web pages, IST National Contact Point pages. The CD ROM has been distributed (700 volumes) at the IST2000 conference in Nice, France.

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 580 partners (mainly Czech small and medium companies in the area of IT) with active interest in the EU IST programme.
- We have organised 53 individual consultations with some of these companies in 2000.
- General publicity of the programme in CZ: [95], [81], [82].

8.5 Notebook for the Blind

A novel version of a notebook for blind people has been prepared and presented by R. Matulík.

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.

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