Head of Department: Miroslav Kárný — decisions under uncertainty, e-mail: school@utia.cas.cz

Secretary: Jaroslava Hradcová — e-mail: hradcova@utia.cas.cz

Research Fellows:

Lubomír Bakule	–	control of large-scale systems e-mail: bakule@utia.cas.cz
Luděk Berec	–	structure estimation e-mail: berec@utia.cas.cz
Jindřich Bůcha	–	knowledge-based systems and learning e-mail: bucha@utia.cas.cz
Josef Böhm	–	robust control algorithms e-mail: bohm@utia.cas.cz
Hong Gao	–	signal processing in telecommunication e-mail: gao@utia.cas.cz
Tatiana Guy	–	hybrid controllers, multi-rate control e-mail: guy@utia.cas.cz
Ladislav Jirsa	–	statistics in biophysics e-mail: jirsa@utia.cas.cz
Ferdinand Kraffer	–	robust control of multivariable systems e-mail: kraffer@utia.cas.cz
Rudolf Kulhavý	–	recursive nonlinear estimation e-mail: kulhavy@utia.cas.cz
Emmanuelle Legrand	–	physical models, web pages e-mail: legrand@utia.cas.cz
Ivan Nagy	–	transportation control e-mail: nagy@utia.cas.cz
Petr Nedoma	–	software engineering e-mail: nedoma@utia.cas.cz
Petr Pecha	–	radiation protection e-mail: pecha@utia.cas.cz
Jiří Rojíček	–	robust control design e-mail: rojicek@utia.cas.cz

PhD students:

Květoslav Belda	–	control of parallel robots e-mail: belda@utia.cas.cz
Petr Gebouský	–	modelling of dynamic processes e-mail: gebousky@utia.cas.cz
Petya Ivanova (CEGS)	–	nonlinear systems for prediction e-mail: ivanova@utia.cas.cz
Nataša Khailová (CEGS)	–	computer-aided design e-mail: khailova@utia.cas.cz
Li He (CEGS)	–	multivariate data analysis e-mail: heli@utia.cas.cz
Václav Šmídl	–	analysis of multivariate data e-mail: smidl@utia.cas.cz
Ludvík Tesař	–	nonlinear recursive estimation e-mail: tesar@utia.cas.cz
Markéta Valečková	–	estimation of Markov chains e-mail: valecko@utia.cas.cz

Year 1999 has been full of changes within the Department staff. It was "harvesting" year for PhD thesis. Ing. H. Gao, PhD, Ing. T.V. Guy [10], Ing. F. Kraffer, PhD and Ing. J. Rojíček, PhD defended their thesis. Mgr. L. Jirsa [19], Ing. L. Tesař [42] and Ing. P. Ivanova have submitted them. N. Khailova and M. Valečková will submit them (hopefully) soon. Thus it is not surprizing that a new generation of PhD students joined us (K. Belda, Li He, P. Gebouský and V. Šmídl). Some students (M. Králík, A. Regner and S. Pěnička) found that there are other interesting things in life than science and left us. We wish them all good luck in life. Creation of Signal Processing Department formed by our former members working with Dr. J. Kadlec is the major change encountered. We wish them success.

Activities of the Institute include cybernetics and informatics as the fields dealing with analysis and design of systems generating predictions, making decisions or controlling other systems. Our Department inspects systems that have the ability to modify their behaviour in correspondence with the changing environment or operating conditions. This essential feature enhances the efficiency of the systems performing the tasks listed above. We have been active in this area for decades and we have reached significant conceptual, theoretical, algorithmic, software and application results. This history is reflected in special issue of the journal Adaptive Control and Signal Processing devoted to Václav Peterka, founder of our Department [21]. Also, his seminal work on self-tuners was reprinted. Gradually, the Bayes-based theory of decision making under uncertainty [25, 35] has become fixed – and successful – methodological kernel of our work. The interplay between theory and always limited computing power is the leitmotiv of our current research.

- We learn what complexity means by solving demanding problems in radiation protection, in transportation, in technological systems, in nuclear medicine etc.
- We gradually improve our know-how in order to widen the applicability of "classic" adaptive systems to complex cases.
- We inspect theoretically possible new approaches to the construction of adaptive systems.

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

Grants and Projects

The results described below have been obtained thanks to the continued effort of the research team. The achievements would be impossible without additional support from many sources. The following list is meant as an acknowledgment.

- L. Bakule – *Robust decentralized control of large-scale systems* (GA AV ČR A2075802)
- J.Böhm – *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. Guy – *Hybrid self-tuning controller* (GA ČR 102/00/P045)
- M. Kárný – *Research and Education Centre in Adaptive Systems: pilot project* (GA ČR 102/99/1564)
- M. Kárný (J. Mošna, ZČU, Plzeň) – *New approach to optimality and adaptivity of uncertain systems* (GA AV ČR A2147701, successfully finished)
- M. Kárný – *Fault Detection and Isolation - Cooperation with Slovenia* (MŠMT ČR ME 245/1998)
- F. Kraffer – *Algebro-geometric methods for polynomial matrix operations with applications in control system design* (GA ČR 102/99/D033)
- P. Nedoma – *Enhancement of the EU decision support system Rodos and its customisation for use in Eastern Europe* (Copernicus PL963365, [Rodos], successfully finished)
- P. Nedoma – *Adaptive systems: theory, algorithms and software for practise* (GA ČR 102/97/0118, successfully finished)

University Courses

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

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

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

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

International Cooperation and Travels

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

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

- L. Bakule
  long-term stay at UPC, Barcelona, Spain,
  5th ILAS Conference, Barcelona, Spain (invited lecture),
  9th IFAC/IFIP/IMACS/IFORS Symposium on Large Scale Systems, IPC member,
  Member IFAC TC Large Scale Systems
- J. Böhm
  lecture in CSCC'99, Athens
  lecture in Process Control'99, Tatr. Matliare
- J. Bůcha
  lecture Process Control'99, Tatranske Matliare
  study visit, participation on IJCAI'99, Stockholm [3]
- H. Gao
  lecture, American Control Conference, San Diego, USA
  research visit, Mondragon University, Spain
- T.V. Guy
  lecture, European Control Conference, Karlsruhe, GER
  study visit, Josef Stefan Institute, Ljubljana, SLO
- M. Kárný
  preparation of IST project Prodactool, Vien, Austria
  preparation of IST project Prodactool, Reading, UK
- F. Kraffer
  lecture, 7th IEEE Med, Haifa, Israel,
  invited lecture, Dept. Appl. Math., E.T.S.I.T., UPV, Spain
- R. Kulhavý
  lecture, IFAC World Congress, Beijing, China
- P. Nedoma, P. Pecha
  Rodos coordination meeting, Rhodes, Greece
- L. Tesař
  lecture, European Control Conference, Karlsruhe, GER

RESULTS

Clustering Improving Operator's Performance Sensors installed on complex processes (rolling mill, transportation system, computer supported medical diagnostic system etc.) offer to the operator a lot of data which should be used for an efficient maintenance of the process in question. The resulting performance depends heavily on the skills and mood of the operator. Thus it is desirable to provide an advisory system that drives him to high performance areas and warns him against probable system misbehaviour. An original theoretical and algorithmic basis of such advisory system was elaborated within 1st Phase Esprit project ProDacTool and formed firm basis of the full scale EU Project IST-1999-12058. It is based on the following idea: the differences in operation quality are believed to manifest themselves in different modes of the distribution of the observed data. This distribution is approximated by a mixture of unimodal distributions (components). Each component is qualified by the expected performance and the best one provides a basis for the advisory system: the operator is shown apropriate univariate cross-sections on it. The efficiency of this approach has been demonstrated on simulated and real rolling mill data. Its success stems from our ability to efficiently perform mixture estimation in high dimensional spaces (say 50 000 records each containing 40 variables). It was achieved by a novel combination of an efficient Mean-Tracking algorithm with quasi-Bayesian estimation of mixtures. The latter algorithm has been recently extended to mixed continuous and discrete variables and applied to fault detection and isolation [25, 33].

Computer-Aided Design of Adaptive Controllers
Adaptive controllers optimizing quadratic criterion with the help of recursively identified linear models having Gaussian process noise (LQG) proved repeatedly their full scale applicability. Their efficient implementation is, however, nontrivial.

The ambitious project of their computer-aided design launched several years ago has been succesfully finished for single-input single-output systems. The MATLAB toolbox ABET99 [34] is now available for complete "batch" design of adaptive controllers. The toolbox functions converts system measurements, user's knowledge, objectives and restrictions into a completely pre-tuned controller. The design result is a C-encoded function that is implemented in real-time control.

The ideas of the toolbox object-oriented design have been summarized in [35]. It offers a methodology and software tools for design of complex decision making toolboxes.

A project of an *interactive* design of adaptive controllers, DESIGNER 2000, continued and was finished. It dealt mainly with design of graphical user interface and the elicitation and utilization of knowledge in controller design [4].

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

Incorporation of prior knowledge. The user's prior knowledge about the system to be controlled together with data from preliminary experiments are converted into a prior model characterizing unknown parameters involved. Experience with the relevant algorithm for the conversion is described in [31, 32]. The algorithm weights the processed knowledge items so that a suitable compromise is found in spite of their imprecise, repetitive and contradictory nature. This:

- increases the chance to estimate a good model structure,
- serves for initiation of on-line estimation and
- provides an alternative model needed for the generalized forgetting which is used to make the adaptation robust.

Refinement of sequential stopping rule. A substantial part of evaluations performed in the discussed area relies on simulations. They should provide reliable estimates of inspected quantities. Thus they should rely on long runs. The simulation length decides on computational time which can easily become excessive. Thus a compromise is needed. This stimulated development of a sequential stopping rule that balances the gained precision and computational load. This rule was proposed formerly within a classical theory of sequential stopping on a universal model relying on ergodicity of the inspected process. This rule was implemented into ABET99 system and successfully experimentally verified for efficiency and reliability.

Advances in the control design. General algorithm for LQ synthesis, which is based on input-output models has been extended for MIMO systems. The technique of tuning the controller [18], available for SISO systems is gradually transfered to the MIMO version. Basic blocks of Matlab and Simulink MIMO Toolbox were created.

Spline-based adaptive LQ hybrid controllers provide complement to the discrete-time controllers. The main idea of the proposed controller is to combine the convolution modelling of continuous controlled system and piecewise approximation of signals. The approach uses a spline approximation of signals and continuous time quadratic loss function. Thus, the gained controller respects continuous-time evolution of the controlled system as well as the discrete-time nature of the controller. In comparison with the traditional solutions, they should reach higher control quality by filtering that reflects properties of involved signals [9, 10, 11].

Extensive testing of LQ adaptive controllers. Adaptive and non-adaptive LQ controllers have been implemented in an LQ toolbox for Matlab and Simulink. The implementation includes the original extensions like data-dependent penalizations. Extensive tests performed with this toolbox and documented in [17] help the user:

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

Functionality and reliability of DESIGNER 2000 has been tested systematically. The majority of tests aimed to detect the role and influence of prior information on control design quality [26].

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

Modelling and identification of traffic systems

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

Generally, we deal with in modeling, identification and control of traffic micro-regions which can be composed together creating large traffic networks on the basis of Bayesian statistics [24]. As control actions, we consider use of the periods of signal lights in the crossroads of the region.

The measured data reflect intensities and densities of traffic flow. Detectors placed under the surface of the roads near crossroads provide them.

Specifically, we consider the following tasks:

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

Data filtration and traffic prediction. The existing measuring devices are often unreliable and improperly placed. Thus data filtration and elimination of superfluous data are necessary. Piece-wise modelling of signals studied in connection with hybrid controllers [10] provides the basic filtering tool. It also serves for prediction of traffic using almost static model and offset modelling periodicities during the week. Data reduction is based on weighted variants of principal component analysis we learnt in connection with image processing in nuclear medicine [40].

Identification of directional relations. Knowledge of proportions in which cars are divided in average in crossroads is a necessary mean for constructing models of traffic areas from single crossroads or traffic networks from single areas. The directional relations are described by static multivariate regression model for which the algorithms of Bayesian identification [34] can directly be used.

Traffic state estimation. For complete description of the state of traffic, intensity and density of traffic flow are necessary. They are represented by points in the state plain. The typical states of traffic can be recognized as clusters in the plane. For modeling the mixture model with components corresponding to particular clusters is used. Identification not only searches for the proper positions of clusters but gives also current prediction of the active cluster. It performs classification [33]. The idea can be extended from the plain to high-dimensional space with many measured variables [25].

Robust Control of Multivariable Systems

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

Principal reasons for the restricted applicability of polynomial matrix methods are numerical unreliability and inability to compute system-theoretically relevant solutions to various polynomial matrix operations like linear and quadratic equations. Publications [27] and [28] 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.

Decentralized Control of Large-Scale Systems

A new extension of the Inclusion Principle has been achieved for quadratic control of linear time–varying dynamic systems. The results are based on a general structure characterization of complementary matrices involved in the input-state-output Inclusion Principle by [8], which enables the formulation of explicit conditions on the complementary matrices that are significantly easier than the conditions considered up to now. Moreover, these conditions offer much more flexible choice of complementary matrices both for analysis and synthesis of control problems. This extension of the Inclusion Principle has been adopted on the LQ control design by using overlapping decompositions in [7]. It includes an original generalization of pairs composed of system and criterion. New results concern quadratic optimal control of both general LTV systems and commutative class of LTV systems. Particularly, only implicit conditions have been derived for general LTV systems because the transition matrix in expansion containes complementary matrix implicitely. To derive explicit conditions, the specialization on a commutative class of LTV systems has been used. It has been shown that the extension of quadratic optimal control from LTI to LTV commutative systems is possible. Moreover, the advantage of this new approach has been demonstrated when comparing it with standard contraction-expansion procedures for optimal control by using aggregations and restrictions. Further, new existence conditions have been proved for expansion-contraction forms ensuring simultaneuos controllability-observability of both subsystems overall systems in expansion.

The results on H_∞ decentralized control design by using the Riccati equation approach by [6] have been tested on simulation the control design of a building structure under earthquake excitation. Variouos decomposition strategies have been considered, mainly in the context of matching conditions and locations of actuators. Selected results have been presened in [5].

Memory-Based Models in Control & Optimisation

The recent progress in database and computer technology makes it possible to use for control and optimisation of technological processes the whole process history. Being more flexible and faster than a global model and more precise and robust than a local (recent-data) model, memory-based approach offers an attractive alternative to the current paradigms. The paper [29] outlines the traditional view of local regression, shows its Bayesian extension and discusses practical choices affecting data retrieval and smoothing. Memory-based methods are especially appropriate for autonomous systems functioning in environments that are not known in advance or which are changing and in which the designers will not be able to tune the system parameters during operation. We approach the problem of system identification through the memory-based learning paradigm. If there is a continuous stream of new training data intermixed with queries, as is the situation ind ynamical system identification, it is less expensive to train and query a memory-based method than it is to train and query a global non-linear parametric model. We shown that the memory-based method is a viable approach to fault detection and diagnosis. Preliminary studies prove it as more reliable for pattern recognition than some of the traditional methods. Some aspects of practical implementations (dealing with locally inadequate amounts of training data, methods for assessing the quality of the estimation, filtering of noise, identify ingoutliers, automatic tuning of parameters) are considered. Finally, we explore an approach to dealing with practical fault detection scenarios when the available database is huge.

Fault Detection and Isolation
Use of realistic models for on-line supervision of production processes increases significantly quality of fault detection and isolation (FDI) techniques. It calls, however, for a deeper understanding of the FDI problem, for development of adequate data processing techniques and software tools. A conceptual Bayesian solution of FDI was summarised in [23]. MATLAB toolbox developed in connection with aformer COPERNICUS project and in co-operation with Slovenia is described in [41]. It contains mainly multmodel based techniques that can be compared with built in classical methods. Multi-model techniques rely heavily on efficient numerical solutions. Bootstrap techniques are adapted and extended in [42, 22].

Information Geometry of Nonlinear Estimation
The lack of an analytical solution to Bayesian identification of non-linear or non-Gaussian models gave birth to a multitude of approximation algorithms. It is quite difficult for the user to compare the existing options and make an appropriate choice. Additional insight can be gained from the fact that estimation itself is an approximation problem, namely that the posteriordensity is closely related to the information divergence between the empirical and model distributions of observed data. The empirical distribution, the family of model distributions and the information divergence between the empirical and model distributions represent three major ingredients of the estimation problem. Any approximation of the Bayesian paradigm necessarily affects at least one of these objects. Following this pattern, in [30] we present three approximation paradigms: based on local weighting of observed data, reduction of the model family and direct

approximation of the information divergence.

Integration of all Cognitive Functions

Utilization of knowledge plays an important role in systems developed in our Department. We need to aid and extend our algorithmic solutions by knowledge-based approaches and, in the outlook especially, by the support of knowledge acquisition. The corresponding areas of knowledge representation and utilization are well developed, and knowledge creation is well developed for applications covering relatively simple systems. Due to our orientation on real applications the extension of knowledge creation, i.e. (machine) learning to the areas of complex systems is very suitable.

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

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

This is a very complex task and it is, by the way, impossible to describe it precisely, in limited space, here. In the range of "all available knowledge", it is also necessary to use knowledge how to cope with complexity. Also, for example, the solution relies on knowledge from object-oriented technology, computer aided software engineering approaches and tools, Unified Modeling Language, uncertainty and inconsistency processing etc. [1, 2].

Customisation of the RODOS system for ČR

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

Profound analysis of the RODOS food-chain module from the point of view of its use for the Czech territory was done [37] including the new definition of radioecological regions for the whole country. The results were also delivered into the joint EU report [36] dealing with the review of the adequacy of RODOS food-chain and dose calculations for European scale. Collection of required data for each radioecological region of CR and their reprocessing and integration into RODOS are described and sent for merging with European data for other regions.

Quality assurance of the product was extended to the customisation tasks including QA of local data [37]. Stepwise improvements of complex model parameters on the basis of co-operation with external expert teams has been accomplished. Data preprocessing subsystem has been developed for purposes of missing gridded data reconstruction. Compliance of the RODOS design with the governmental regulations fixed in the new Czech Atomic law has been checked.

In connection with the RODOS project, methodology and software tools for partial evaluation of radiological impact on population initiated by both accidental and routine atmospheric radioactive releases have been thoroughly examined. Results of comparison analysis between various codes are reviewed in [38].

Estimation Tasks in Nuclear Medicine

The strength of the Bayesian estimation methodology becomes visible when a high estimation quality is required using a few uncertain data and a vague but non-trivial prior information. Its use has contributed to reliable estimation of various quantities met in nuclear medicine, mostly describing the dynamics of accumulation/elimination of ^{131}I. The research has reached advanced stage so that the resulting data processing [13, 19, 20], is now practically tested in connection with the treatment of thyroid gland diseases [**?**] [12]. Non-traditional ways of accumulation/elimination modelling [14], [15] brought a novel view on some formerly observed discrepancies between diagnostic and therapy evaluations [16]. They are being implemented in system JOD*NEW* [43], [44].

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