Department of Adaptive Systems

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Profile

Research Topics

The Department of Adaptive Systems is the largest department at the Institute with wide-ranging research area. The major research programme at the Department concentrates on the design of decision-making systems, which are able to modify their behavior according to the changing environment or operating conditions. This essential ability, called *adaptivity*, enhances the efficiency of such systems. Decades of systematic research brought significant conceptual, theoretical, algorithmic, software and application results. An applicability of adaptive systems has been greatly extended towards complex cases. It is reached by improving the classical adaptive systems as well as by inspecting new approaches to their construction.

Departmental "know-how" contributes to solution of a number of national and international research projects, running in collaboration with industry and government agencies. The interplay between theory and limited computing power continues to be the common issue behind variety of the Department's research projects, which include transportation, management and control of technological systems, nuclear medicine etc.

Increasing complexity of problems addressed directs considerable part of the research towards distributed control of large scale systems and normative decision-making with multiple participants. Important foreseen applications concern modelling; control of robot colonies and electronic democracy.

The more detailed descriptions of specific research projects, information about members of the Department, their publications, and the companies and agencies, which sponsor their research can be find at www.utia.cas.cz/AS.

International Cooperation

The international collaboration is supported by agreements of Academy of Sciences and Ministry of Education of the Czech Republic. They are also driven by the project Edukalibre within EC programme Socrates (http://edukalibre.org) and ESF (European Science Foundation) project Towards Electronic Democracy. The Department's major partners are in Bulgaria, France, Germany, Hungary, Italy, Ireland, Slovakia, Slovenia, Spain, Switzerland, UK.

University Boards

M. Kárný is a member of three boards for doctoral theses defenses at the Czech Technical University and the University of West Bohemia.

Editorial Boards

Lubomír Bakule — Intersections

Lubomír Bakule, Zentralblatt für Mathematik

Miroslav Kárný — International Journal of Adaptive Control and Signal Processing

Miroslav Kárný — International Journal of Knowledge-Based Intelligent Engineering Systems

Miroslav Kárný — KES journal, associate editor

Miroslav Kárný — International Series on Advanced Intelligence, advisory board

Representation in International Societies

Lubomír Bakule, member of Technical Committee on Large Scale Complex Systems, IFAC

Lubomír Bakule, IPC member and invited session organizer, the 10th IFAC International Symposium on Large Scale Systems, Japan

Josef Böhm, member of Technical Committee on Controller Design, IFAC

Tatiana V. Guy, Rudolf Kulhavý, senior members of IEEE

Miroslav Kárný, Rudolf Kulhavý, members of Technical Committee on Stochastic Systems, IFAC

Miroslav Kárný, member of steering committee of ESF project "TED – Towards electronic democracy"

Petr Zagalak, member of Technical Committee on Linear Systems, IFAC

Recent Activities

Grants and Projects

The following list acknowledges variety of departmental sponsors.

L. Bakule – *Decentralized control of large-scale systems* (GA AV ČR A2075304)

L. Bakule – *IFAC.* (MŠMT, INGO, 1P04LA209)

K. Belda – *Implementation of control in redundant parallel robotic structures* (CTU IG 0406413, concluded)

J. Böhm – *Design of adaptive control systems*. (GA ČR 102/02/0204, concluded)

J. Böhm – *Redundant drivers and measurements for hybrid machine tools* (GA ČR 101/03/0620)

T. V. Guy – *Development of multiple model adaptive systems* (GA ČR 102/03/P010)

T. V. Guy – *Control and supervision of technological processes by using mixture modelling* (MŠMT ME 26-2003-04)

L. Jirsa – *Intelligent decision support of diagnosis and therapy in nuclear medicine by Bayesian processing of uncertain data and probabilistic mixtures* (AV ČR 1ET 100 750 404)

M. Kárný – *Quantitative lympho-scintigraphy for diagnostics and therapy of upper limb lymphedema* (IGA MZČR NC7601-3/2003)

M. Kárný – *TED – Towards electronic democracy* (ESF project)

M. Kárný – *BADDYR: Bayesian adaptive distributed dynamic decision making* (AV ČR 1ET 100 750 401)

I. Nagy – *Implementation of optimization algorithm controlling traffic lights* (Eltodo a.s., contract)

I. Nagy – *Edukalibre: Promotion of Open and Distance Learning Information and Communication Technologies in the Field of Education* (110330-CP-2003-ES-Minerva-M)

I. Nagy – *Transportation control in the centers of historical cities* (MD ČR 1F43A/003/120)

P. Nedoma, I. Nagy – *Dynamic clustering: theory, algorithms and software* (GA ČR 102/03/0049)

P. Nedoma – *Dynamic clustering for control of complex processes* (AV ČR S1075351)

P. Pecha – *Development and implementation of advanced tools for modelling of radionuclide distribution in environment* (SÚJB, contract no. 1047)

P. Pecha – *EVANET-HYDRA: Radionuclides in water environment* (EU-FIGE-2001-20125)

L. Tesař – *Artificial Intelligence methods in diagnostics from medical images* (AV ČR 1ET 101 050 403)

P. Zagalak – *Programme Barrande* (MŠMT ČR no. 2004-043-1)

Teaching and Supervising Activities

University Courses

Traditionally, the Department tightly collaborates with Czech Technical University. The current teaching programmes include the courses:

Probability Theory and Statistics given by I. Nagy, J. Homolová, P. Němcová at the *Faculty of Transportation Sciences*.

Tutorials from Technical Documentation given by K. Belda and *CAD of Control Systems* given by P. Nedoma at the *Faculty of Electrical Engineering*.

Predictive Control given by J. Böhm and *Dynamic Decision Making* given by M. Kárný at the *Faculty of Nuclear and Physical Engineering*.

Supervising

P. Gebouský and V. Šmídl defended their PhD theses [7, 17]. M. Novák is polishing his thesis. K. Belda complements his education by pursuing his second PhD degree. J. Andrýsek and J. Kracík continue successfully and they plan to submit their theses during the year 2005. Substantial progress of L. Pavelková and J. Homolová promises high quality of their theses. P. Němcová started her postgraduate studies.

Conferences, International Contacts

Conferences – Organization

The workshop *CMP'04: Multiple Participant Decision Making: Theory, algorithms, software and applications* was organized within TED project (see http://bayes.escet.urjc.es/ted) supported by ESF. This workshop is the sixth in a series of CMP (Computer-Intensive Methods in Control and Data Processing) workshops traditionally organized by the Department. It brings together specialists active in academic research and industrial developments to discuss the state-of-the-art, new research results, perspectives of future developments and innovative applications relevant to the common problem known as "curse of dimensionality".

The last workshop aimed on: (i) formulation of the complexity-influenced problems within areas of multiple-participant decision making; (ii) offering techniques developed in disparate research and application areas that

can be used in solving these problems, see http://www.utia.cas.cz/AS/CMP04 and [2].

Conferences – Participation

J. Andrýsek: CMP'04: Multiple Participant Decision Making, Prague

J. Andrýsek: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

L. Bakule: The 10th IFAC/IFORS/ IMACS/IFIP Symposium on Large Scale Systems: Theory and Applications, Osaka, Japan

L. Bakule: The 6th IASTED International Conference on Intelligent Systems and Control, Honolulu, USA

L. Bakule: The 43rd IEEE Conference on Decision and Control, Nassau, Bahamas

K. Belda: The 10th International Conference Radioelectronics, Electronics and Energetics, Moscow, Russia

K. Belda: The 4th Chemnitz Parallel Kinematics Seminar, Chemnitz, Germany

K. Belda: CMP'04: Multiple Participant Decision Making, Prague

K. Belda: The 6th International Scientific-Technical Conference Process Control 2004, Kouty nad Desnou

K. Belda: The 3rd International Congress on Mechatronics MECH2K4, Prague

K. Belda: The 10th IEEE International Conference on Methods and Models in Automation and Robotics, Miedzyzdroje, Poland

K. Belda: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

K. Belda: The 12th Conference "MATLAB 2004", Prague

J. Böhm: The 6th International Scientific-Technical Conference Process Control 2004, Kouty nad Desnou

J. Böhm: The 2nd IFAC Symposium on System, Structure and Control, Oaxaca, Mexico

J. Böhm: CMP'04: Multiple Participant Decision Making, Prague

P. Gebouský: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

T.V. Guy: CMP'04: Multiple Participant Decision Making, Prague

T.V. Guy: The 12th Mediterranean Conference on Control and Automation, Kusadasi, Turkey

T.V. Guy: The Complex Systems Intelligence and Modern Technological Applications, France

M. Kárný: CMP'04: Multiple Participant Decision Making, Prague

M. Kárný: The FET FP7 Workshop: New Directions in ICT in FP7: Grand Challenges for Basic Research, Brussels, Belgium

J. Kracík: CMP'04: Multiple Participant Decision Making, Prague

J. Kracík: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

F. Kraffer: CMP'04: Multiple Participant Decision Making, Prague

F. Kraffer: The 6th International Scientific-Technical Conference Process Control 2004, Kouty nad Desnou

F. Kraffer: The 12th Mediterranean Conference on Control and Automation, Kusadasi, Turkey

F. Kraffer: The 2nd IFAC Symposium on System, Structure and Control, Oaxaca, Mexico

J. Homolová: CMP'04: Multiple Participant Decision Making, Prague

P. Němcová: CMP'04: Multiple Participant Decision Making, Prague

P. Němcová: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

M. Novák: CMP'04: Multiple Participant Decision Making, Prague

M. Novák: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

M. Novák: The 6th International Scientific-Technical Conference Process Control 2004, Kouty nad Desnou

L. Pavelková: CMP'04: Multiple Participant Decision Making, Prague

P. Pecha: CMP'04: Multiple Participant Decision Making, Prague

P. Pecha: The 9th Conference: Harmonization within Atmospheric Dispersion Modelling for Regulatory Purposes, Garmisch-Partenkirchen, Germany

P. Pecha: The 26th Radiation Protection Days, Luhačovice

E. Suzdaleva: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred, Hungary

V. Šmídl: CMP'04: Multiple Participant Decision Making, Prague

V. Šmídl: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred – Hungary

L. Tesař: The 5th International PhD Workshop on Systems and Control. A Young Generation Viewpoint, Balatonfüred – Hungary

L. Tesař: Norwegian Conference on Image Processing, Stavanger, Norway

L. Tesař: The Congress of European Thyroid Association, Istanbul, Turkey

L. Tesař: Endocrynology Days, Piešťany, Slovakia

L. Tesař: CMP'04: Multiple Participant Decision Making, Prague

International Contacts

The Department is always host to a number of visiting academics from the international community: F. M. Duarte (CL), J.J. Loiseau (FR), A. Magyar (HU), S. Popova (BG), V. Lyubenova (BG), A. Quinn (IE), K. Warwick (UK), E. Wagneur (FR), A. Bodini (IT), F. Ruggeri (IT).

Prof. K. Warwick (UK) and Dr. A. Quinn (IE) spent a substantial part of their sabbaticals with the Department.

Stays abroad of our members were also project driven and included long stays:

L. Bakule, Technical University, Barcelona, Spain, invited stay

V. Šmídl, Trinity College Dublin, Ireland preparation of PhD thesis

P. Zagalak, Universidad de Chile, Santiago, Chile, invited stay

P. Zagalak, CINVESTAV del IPN, Mexico D.F., Mexico, AV ČR – CONACYT agreement

as well as short-term stays

J. Andrýsek, J. Kracík, Italian National Research Council, Milano, Italy – study stay within a common project

K. Belda, Computer and Automation Research Institute, HAS, Hungary – study stay within a bilateral project

M. Kárný, Josef Stefan Institute, Ljubljana, Slovenia – cooperation within a common project

M. Kárný, Brussels, Belgium – preparation of topics for 7th Framework Programme

M. Novák, Institute of Control Systems Research, Bulgaria – cooperation within a common project

E. Suzdaleva, L. Pavelková, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal – coordination meeting of Edukalibre project

P. Zagalak, Institut de Recherche en Communications et Cybernétique de Nantes, CNRS UMR 6597 – cooperation within a common project.

Results

Dynamic Advising and Adaptive Control

The theory of Bayesian decision-making, based on mixture models and fully probabilistic design (FPD) of decision strategies, has been further extended. It considers: (i) development of FPD for the state space models, which completes theoretical basis for the design of decision strategies; (ii) development of FPD for design objectives, represented by a mixture, which gives a way to solve multi-objective decision-making problem [8]; (iii) Bayesian model validation with cutting between learning and validation data included into the tested hypotheses, that enhances reliability of the dynamic model gained by learning [11].

Distributed Bayesian Decision-Making

This research exploits the basic concepts of Bayesian decision-making theory, developed for a single participant.

This new direction has long-term objective to develop complete theoretical and algorithmic basis for multi-participant decision-making. The gained preliminary results include: problem formulation; detailed description of the possible cooperation scenarios; analysis of communication ways within multi-participant environment [10] and structural design of a new software framework for this type of problem.

These results are expected to be used in related projects like TED (ESF) and hierarchic urban traffic control.

Feasible Bayesian Estimation

A new projection-based estimation of complex models was proposed and successfully applied to the important class of normal mixtures [1]. Comparative testing of the new estimation algorithm on a large set of simulated examples has shown better quality than well established existing algorithms.

An estimation of model structure with non-nested prior information, correcting long-lasted deficiency of former solutions, has been designed [14].

Prior Design of Adaptive Controllers

Computer-aided design of adaptive controllers based on linear models and quadratic criterion has for decades been an important part of the Department's research. Much of the work is finished and recent successful application to the control of yeast production indicates that scalar version is ready for wide use.

The remaining part of research in this direction concerns multivariate version of the design. In particular, development of efficient techniques for conversion of user's objectives into appropriate penalization matrices. Preliminary results cover selection of penalization weights in quadratic loss function so that constraints on involved signals are respected as much as possible.

Decentralized Control of Large-Scale Systems

An original extension of the Inclusion Principle has been derived to uncertain nominally linear discrete–time systems with quadratic costs using the concept of quadratic guaranteed cost control. The uncertainty is assumed to be norm-bounded in both the state and input matrices. The main contribution is the derivation of conditions under which a quadratic guaranteed cost control designed in the expanded space can be contracted to the initial system preserving simultaneously the value of the cost functions. The control law is designed in the expanded space by using the LMI approach. The specialization of the results on feedback control with decentralized information structure constraints is given. [4].

Overlapping quadratic optimal control of linear time-invariant systems and a commutative class of continuous-time time-varying systems has been recently developed by using a generalized structure of complementary matrices. It has been shown that these structures offer a powerful and effective mean for decentralized control design for these classes of systems. These structures are presented now for general linear time-varying discrete-time systems. The results presented here concern the transition matrices and explicit conditions on complementary matrices for this class of systems. It essentially differs from continuous-time linear time-varying systems, where general results hold only for aggregations and restrictions. A guideline for their selection is given, [5].

Complexity reduced control design is presented for a class of uncertain time-delayed symmetric composite systems. Both state and input delays are considered. The construction of reduced-order systems is presented. Then the quadratically stabilizing output controller is designed for this model using the Riccati equations approach. It is proved that the implementation of this controller into each subsystem leads to the quadratic stability of the overall closed–loop system, [3].

Linear Systems

The theory of linear systems has reached its maturity; in spite of that there exist some problems that have not been solved yet, and which represent a real challenge for control theoreticians and mathematicians. Among them especially the problems of model matching, decoupling, and eigen-structure assignment were under main attention. More particularly a special case of model matching, which is a generalization of the well-known feedback simulation problem, has been solved [13]. It should be noted that the problem remained unsolved for almost 30 years.

Numerical Methods for Linear Systems

A reliable implementation of control system design based on polynomial approach to multivariable linear time-invariant systems has been the objective of research in linear and quadratic polynomial equations. Recently obtained original results in the particular problems of design for proper compensators in a unity closed loop with a strictly proper plant and in iterative spectral factorization for linear quadratic methods had been examined. They were applied to several multi-variable systems in the wider area of electro-mechanical motion control applications. Spin-off results include a generalization to rectangular matrices of the linear equation for the design of proper compensators. The generalization is useful for estimating those internal signals in a plant-actuator-sensor model of a physical system that for physical, economic or safety reasons are not measured on that system.

Software System Mixtools

This research directs towards creation of software system, which represents a full algorithmic image of Bayesian single participant decision-making, developed at the Department. Although the current version solves the task considered, the theoretical investigations continue and call for regular complementing and upgrading of Mixtools. The designed solutions cover: (i) filtered version for learning; (ii) graduate learning, illustrated on case studies (see experimental supplement to the book [9]); (iii) experimental case studies [15];

To facilitate the use of the software and eliminate possible communication errors, a unified interface has been designed and tested. It implements full design line from the problem specification, data preprocessing, learning, design of decision making strategies and validation of results.

Libre Software for Free Education

The project Edukalibre, within the European programme SOCRATES - MINERVA, aims to provide free tools for teaching projects from various areas on the web. Our task is to supply advanced course on Bayesian dynamic decision making. The course will cover both the general theory and its application to various specific probabilistic models and decision tasks. A lot of examples has been already prepared and attached to [9].

Hierarchic Urban-Traffic Control

A systematic approach of tackling traffic control problem has been elaborated [12]. The control is designed as hierarchical one. The lowest local level is designed for transportation of micro-region and based on Kalman-filter state estimation combined with linear-programming-based optimal control of dynamic switching model. The second level coordinates micro-regions and the upper level intervenes in exceptional situations like vehicle accidents, etc.

Control Application in Robotics

Predictive control, as one promising alternative to control of parallel robots, was investigated and generalized for different robot structures. Within the described research period: (i) conditions for an exact linearization respecting gravitational forces of vertical robot configurations were investigated; (ii) two selected techniques for eliminating the steady state error problem were tested: a laboratory model of vertical redundant parallel robot structure "Sliding Star" [6] served to this purpose; (iii) two-level control algorithm with nonlinear corrections was developed: it fully utilizes a nonlinear model describing the mechanical robot structure; (iv) the predictive control was adapted for quadratically optimal trajectory planning.

Control of Large-Scale Mechanical Structures

Overlapping reliable 1-out-2 control design decomposition strategy has been improved, corrected and tested for the cable-stayed bridge benchmark problem to satisfy the control design requirements in a more advance way. The bridge has been recently put into the operation in Missouri, USA. It consists of two towers, it has a total length 1.2 km, and the construction has 128 cables. The overall finite element model consists of 838 states. There are available 18 evaluation criteria, which must be simultaneously satisfied in an acceptable way. They include also critical cable tensions as an a priori requirement on the control design.

Customization of the RODOS System

Customization of the EU software product RODOS (Real time Online DecisiOn Support) for nuclear emergency management was successfully finished. Transition to the final RODOS version PV 5.0 was done at State Office for Nuclear

Safety. The connection to online meteorological measurements and meteorological forecasts has been realized in cooperation with the Czech Hydro-meteorological Institute for purposes of atmospheric dispersion modelling in near, middle and far regions [16]. In the field of modelling of radionuclide transport by hydrological pathways the customization of river model RIVTOX has been completed for part of Vltava river and 3-D hydrological model THREETOX was customized for Orlík reservoir. Validation study using far-range model MATCH has been performed and the results were compared with the results of MEDIA code routinely used in CHMI. Some conversion algorithms were developed for data transition into RODOS environment.

Quantitative Lymphoscintigraphy of Arms

The research aims at solving the important diagnostic problem related to the detection of early stages of the secondary lymphedema. A very little amount of measured data available makes the task complex. Novel theory and algorithms developed rely on the simplified modelling of dynamic scintigraphic response on limb regions. First stage tests on real data gave good results and provided further independent evaluation in addition to the clinical conclusions and morphological evaluation [7].

Advising in Nuclear Medicine

Bayesian analysis of the treatment of thyroid gland carcinoma has been extended to advising on therapeutic amount of radioactive ^{131}I administered to a patient. Patients' biophysical records, characterizing their accumulation dynamics of ^{131}I, have been modelled by probabilistic mixture. Full scale experimental use brought the first research feedback [9]. In cooperation with medical doctors, a set of processing variables has been extended. Novel, improved processing algorithms are to be used.

References

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4 Decentralized distributed adaptive systems. 4.1 Multi-agent systems. 4.2 A general architecture for a distributed system of services. 4.3 The most relevant contributions to decentralized distributed adaptive systems. 4.3.1 Contributions related to Cognitive Radio. 4.3.2 Adaptive services in the Cloud.Â Faculty of Electronics, Telecommunications and Information Technology Communications Department. Habilitation. Complexity in Adaptive Systems by Marcel Cremene. The authorâ€™s research activity, following the PhD defense in 2005, is presented from a unied interdisciplinary perspective of complex adaptive systems. The Thesis subject lies at the crossroads of Software Engineering, Optimization Theory, Meta-heuristics, Evolutionary Computing and Game Theory. Verification of Adaptive Systems. April 2016 Final Report. This document is available to the U.S. public through the National Technical Information Services (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov. U.S. Department of Transportation Federal Aviation Administration. NOTICE This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the contents or use Adaptive systems that continuously monitor their own performance and adjust their control strategies to improve it have been studied for more than 50 years. The theory of such systems when the plants (or processes) to be controlled are linear and time-invariant is currently well understood. Numerous methods currently exist to achieve a satisfactory and robust response when the uncertainty in the system is small. During the past 3 decades numerous attempts have been made by workers in the field to extend the methods to systems with larger uncertainties.