**INSTITUTE OF CYBERNETICS**
at Tallinn University of Technology

Institute of Cybernetics at TUT

# ACTIVITY REPORT

## 2000-2003

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# Contents

# PREFACE

Institute of Cybernetics (IoC) is an autonomous research unit at Tallinn University of Technology carrying out basic and applied scientific investigations in control systems, computer science, mechanics and mathematics. IoC comprises researchers, PhD and MSc students and assistant staff, altogether about 80 people. These are people highly motivated by the interest in structure of and principles governing the world, society and technology. To characterize an average member of IoC, I would like to emphasize an individual and independent style of thinking, endeavouring after untraditional approach to explain the world.

IoC was founded in 1960 as a research institute in the Estonian Academy of Sciences. Within the optimization process of Estonian science and development system, IoC was reorganized. Its technological development oriented departments established a private research and development company Cybernetica Ltd, whereas the more basic research oriented part continued as IoC under Tallinn University of Technology.

The spectrum of research fields of IoC has been always rather broad, but for several decades IoC has particularly been the leading Estonian institution in development of new computer systems. After personal computers became widely used in society and systems development changed into an industrial activity, the study fields of IoC have altered. Nowadays, IoC is in fact an institute of applied mathematics investigating utilization of mathematically based methods in a wide area starting from control, material science, and mechanics to computer science and language technology, seeking foundations of modelling techniques. Most of the research concentrates on non-linear models.

The present technical report provides a short overview of the research topics and the most important achievements of IoC in years 2000 - 2003. This period has been successful for the institute. IoC has attracted new financing bodies to support its activities. The budget of IoC has increased about 60% during these years. IoC passed an international evaluation of all its research groups with positive results. Two departments of IoC together with their partner scholars from other Estonian universities and institutes were nominated as national excellent centers in science: the Centre for Nonlinear Studies and the Centre for Dependable Computing. IoC has obtained its first research projects financed by the European Commission. Laboratory of Phonetics and Speech Technology has developed the Estonian speech models up to the level that allows using them in commercial speech synthesizers. As recognition of this result the research team obtained the Estonian National Science Prize in 2002.

All these recognitions of the results of researchers of IoC encourage us to continue the research traditions of the institute directed towards acquisition of new knowledge about nature and technology.

Jaan Penjam
Director

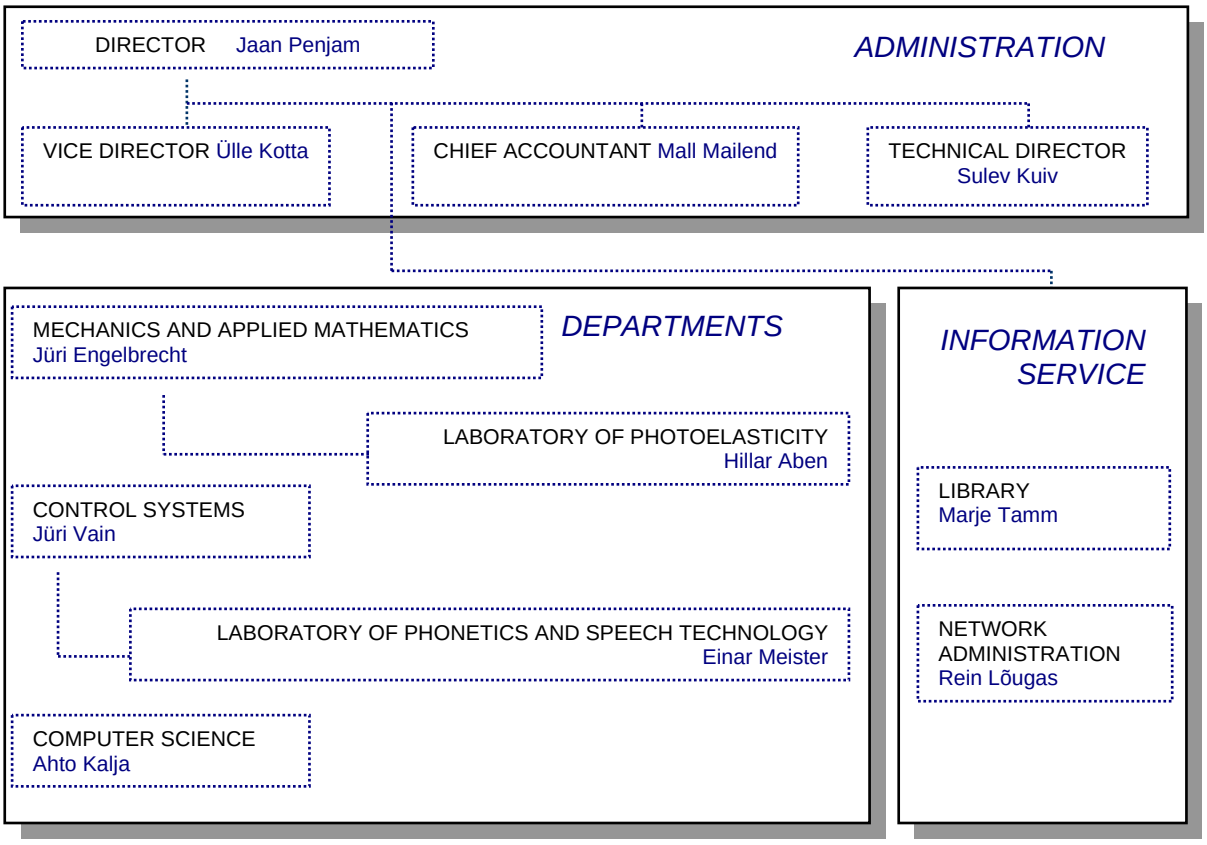
# 1 INTRODUCTION

## 1.1 STRUCTURE OF IOC

At the end of year 2003, 44 persons form the academic research staff of IoC and 37 persons the support staff (technical, professional and administrative). Academic staff includes 5 DSc's, 27 PhD's and 12 MSc's.

| Age | -30 | 31-40 | 41-50 | 51-60 | 60- |
|---|---|---|---|---|---|
| Academic staff | 7 | 11 | 6 | 9 | 11 |
| Support staff | 18 | 0 | 8 | 6 | 5 |

Table 1. Distribution of academic staff in age




## 1.2 EVALUATION OF RESEARCH

The Higher Education Quality Assessment Center of Estonia invites experts from abroad to review and make accreditation recommendations for each research field once in 7 years. Six different research themes were evaluated in 2000-2002.

On April 27th-29th, 2000 the research field "Information Technology and Automatic Control" was evaluated. In IoC the following research fields were assessed

- Knowledge-Based Control and Information Systems (KBC)
- Compositional Specification and Verification of Hybrid Dynamical Systems (HDS)
- A Phonetic Research on the Sound System of Estonian Language (SS)
- Robust and Nonlinear Control Systems (CS)

The overall evaluation judgement of the four fields was Good to Satisfactory. Competence in KBC and CS fields is estimated to be very high and of an international standard.

The expert team recommended to increase the number of publications in internationally well-recognized journals and to put more effort to the development of researchers' skills for coping with practical problems, which would lead to a more active cooperation with the industry. The leading researchers are working only part-time at IoC. Therefore they have double working load in management and they cannot fully devote their energy to the research and development work at IoC. The team suggested the leading researchers to reconsider the division of work between the university and IoC.

On May 24th, 2001 the research field Nonlinear Mathematical Modelling was assessed. The evaluators rated research activities of this field Excellent, and the overall capability of the group as Good, but they stressed the need to attract young people to the group and to send young promising PhD-students abroad, at least for one or two terms.

Between April 17th-21st 2002 the research in mechanics was evaluated. The studies in mechanics in the Institute of Cybernetics are concentrated under the umbrella of the Centre for Nonlinear Studies, which is a focal point for mechanics and applied mathematics in Estonia. The overall capability of three research groups was rated Excellent and Excellent to Good.

The evaluators marked that the very competent senior staff has the capacity of educating at least the double of number of research students from all the fields of mathematics, physics and engineering. The research is well documented in many refereed articles in international journals. The research work in the field of fractality and biophysics is original and it is connected to the present trends of the international research community. The Laboratory of Photoelasticity is highly competent and well equipped. The research of piano hammer and its interaction with the string is successful and of industrial interest.

Evaluators recommended extending the fractality analysis into the dynamics of the economy. Nonlinear time series analyses, predictions, study of undercurrent mechanisms of economical systems are very important fields, and the mathematical tools are already at hand for research group members.

## 1.3 CENTRES OF EXCELLENCE IN RESEARCH

In 2001, the Ministry of Education has initiated the Estonian Programme for Centres of Excellence in Research. The following aims were set up:

- to encourage co-operation between the research groups working in the close or complementary areas;
- to establish the conditions for Estonian centres of excellence to join the international net-work according to the European Union's research policy;

- to create the conditions for high-level research compatible with the strategy of research and development in Estonia.

The Research Competency Council reviewed about 30 applications and those satisfying most of the prerequisites were chosen for the second phase. In the second phase the international peer-reviewing was organized by the Higher Education Quality Assessment Council of Estonia. The final evaluation took place in November 2001 and five outstanding centres together with one centre with the earlier European recognition were nominated to bear the name "Estonian Centre of Excellence in Research". In 2002, a new round of selection was organized and 10 centres including the earlier 6 were selected for a period 2003-2006 in order to promote research in the selected strong fields.

Among these centres were Centre for Dependable Computing (CDC) (head professor Jaan Penjam and Centre for Nonlinear Studies (CENS) (head professor Jüri Engelbrecht). The working groups of IoC play a key role in both centres.

### CDC - Centre for Dependable Computing

CDC unites scientists from different institutions sharing common research interests and working on common themes following a jointly agreed research plan. In fact, the associated research groups have for years constituted an informal research network that, depending on prevailing political and financial situation, has worked together organising all-Estonian seminars, conducting projects for supporting computer sciences higher education (TEMPUS projects) or running international winter schools for graduate students. The research plan of the CDC is in agreement with that of the participating institutions. CDC involves people from seven institutions: IoC at TUT, Department of Computer Science (TUT), Department of Computer Control (TUT), Department of Computer Engineering (TUT), Institute of Computer Science and Institute of Technology from University of Tartu, and Cybernetica AS.

The research areas of the two research groups from IoC at TUT are:

- mathematical foundations and programming language technology;
- formal methods in software engineering.

### CENS - Centre for Nonlinear Studies

The underlying idea for founding CENS in 1999 was to bring under one umbrella the scientific potential of Estonia engaged in interdisciplinary studies of complex nonlinear problems that stem from biophysics, optics, marine physics together with the theory of differential equations have been interwoven into a complex multidisciplinary field called "nonlinear science".

The research areas of the three research groups from IoC at TUT are:

- nonlinear waves including solitonics, phase-transformation fronts and acousto-diagnostics;
- fractality and biophysics including *in silico* modelling of cardiac mechanics and cell energetics, heart rate variability;
- nonlinear integrated photoelasticity.

## 1.4 DIVERSITY OF FUNDING

IoC is funded basically from the three following sources.

- The main part of the funding comes from the governmental budget for basic scientific research.
- The second important sources of funding are the grants of Estonian Science Foundation (ESF) and Estonian Innovation Foundation (EIF)[1]. In the same category of funding belongs also research support from international funding organisations (see Annexes 1, 2, and 3).
- Finally, IoC performs contract-based research and provides services to different customers, including government agencies and industry. Long-term research and development projects are going on with Estonian Traffic Insurance Foundation on analysis of traffic situation and risks of the foundation.

| | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|
| Governmental budget | 4776 | 4790 | 5561 | 5341 +2350*) |
| ESF grants | 1769 | 1914 | 1916 | 1793 |
| Contracts | 834 | 2021 | 1887 | 2511 |

Table 2. Distribution of funding by sources (in thousands of EEK)

*) additional funding for centres of excellence

## 1.5 CO-OPERATION

IoC has developed close and strong informal research contacts with many European universities and research centres. This cooperation has lead to numerous joint publications (see list of publications), and joint projects.

A great number of foreign researchers have visited us (see Annex 8) but in most cases such visits have lasted up to two weeks because of the limited budget of IoC. Some visitors have been working in IoC in the framework of co-operation agreements between Estonian Academy of Sciences and the academies of other countries.

CDC and CENS — two Estonian Centres of Excellence in Research — are joining research groups from IoC and those from Estonian Universities and research organizations.

The project eVikings II has been started in 2002. It is a FP5 IST programme accompanying measures project (IST-2001-37592, Nov. 2002-Apr. 2005). The project aims at strengthening the existing IT-related science and technology strongholds in Estonia and energising Estonia's innovation system by enhanced ability to anticipate future development and manage the related innovation processes.

IoC has been included into the European Scientific Foundation Programme NATEMIS "Nonlinear Acoustic Techniques for Micro-Scale Damage Diagnostics" which concern the

[1] From 2002 Estonian Technology Agency ESTAG

creation of a very broad and interdisciplinary network for the purpose of studying experimentally and theoretically the effects of nonlinearity at a mesoscopic level.

IoC is supporting IT curriculum development and arrangement of advanced graduate courses for Estonian Universities. This work is co-ordinated via IT&CS Education Development Centre for Estonian Universities (CIDEC). CIDEC was founded in 1995 within the framework of EU TEMPUS S_JEP-06145 with active involvement of IoC. Since 1996 via CIDEC Estonian Winter Schools in Computer Science (EWSCS) for graduate students from TU and TUT, where invited lecturers give courses in frontline topics of computer science, have been organised every year in March.

# 2 BASIC RESEARCH

## 2.1 ONTOLOGY ORIENTED PROGRAMMING

Principal investigator: Jaan PENJAM

A goal of this research is the elaboration of a new software technology and related methods, tools and languages oriented to specification domain ontologies, automatic program construction and verification of program properties. The studies are motivated by the bid to get more reliable and efficient systems. The philosophy behind this research is that correctness and efficiency of software system depends much on the quality of specification and technologies used in the process of system development. We believe that to achieve a desired result, the requirements and goals of a system should be specified in (sub)natural languages, at higher logical (abstract and declarative) level using terminology of problem domain. Further developments of the system have to contain as much as possible automatic transformations of specifications into a program code.

The research activities of the research group can be viewed as a collection of studies in the following subfields:

- semantics of programs and languages;
- compositional synthesis and reuse of programs;
- applications of ontology oriented programming.

As a result, several specification languages (both textual and graphical languages) for describing computational ontology of a problem domain were developed during last ten years. The formal semantics of these languages have been defined and analysed. Some automatic program construction methods (known as deductive program synthesis or structural program synthesis) have been developed and implemented in this project. Various knowledge domains are represented by their ontologies – describing concepts and relations between them. A basis for this research lies in mathematical logic, i.e. in pure science. On the other hand, linguistics and semiotics are applied in the domain analysis and knowledge representation. This illustrates the interrelatedness of basic research and applied research, as well as research in humanities and science. Practical results of this symbiosis can be illustrated by the applications like simulation of radar coverage of the coastal area of Estonia and simulation of complex hydraulic systems.

### 2.1.1 SEMANTICS OF PROGRAMS AND LANGUAGES

Principal investigator: Tarmo UUSTALU

The main research directions of the group are logic and algebra as the foundational disciplines of theoretical computer science, and programming language theory (semantics, design, implementation). More specifically, the group is focusing on structural proof theory and type theory, categorical logic, ordinal analysis, algebraic combinatorics, semiring theory and algebraic automata theory, programming language semantics and

programming language implementation, program analysis, incl. typebased methods, semanticsbased program manipulation, languagebased security.

A number of new results has been obtained in the theory of inductive and coinductive types, monads and comonads, with applications to modularity in representing and reasoning about syntax and computations with effects and to typebased termination: A novel structured recursion scheme based on a comonad and a distributive law has been formulated which makes it possible to treat a variety of standard structured recursion schemes as instances of one generic scheme. A general account has been given of the so-called Mendler style of formulating structured recursion schemes where the totality of the function being defined (termination of the program) is ensured by the polymorphic type imposed on the scheme. A strong generalization has been given for the theorem by Adamek and colleagues on non-wellfounded term algebras as free completely iterative monads. CPS and monadic translations have been defined for languages with inductive and coinductive types. Frameworks for representing and reasoning about syntax with variable binding have been studied for non-wellfounded syntax and explicit substitution. A fixed-point-theoretic construction has been given for calculating the coproduct of two ideal monads. This construction enables one, e.g., to calculate the combination of the monads capturing non-determinism and probabilistic choice.

A novel definition of secure information flow has been given which is based on computational rather than information-theoretic independence of the public outputs of a program from its secret inputs. It has been shown how to analyse a program for security in a language with an encryption operator and how to analyse a program for relative security (security on the assumption that some of the outputs of a program are non-secret).

A method for exact static analysis of multi-threaded progams has been developed which avoids state space explosion by use of global invariants. The method has been implemented in a prototype for validation of avionics software.

Several constructive foundational mathematical theories (constructive set theory, Martin-Löf's type theory) have been shown to be realizable into Feferman's explicit mathematics.

A number of results have been obtained on rewriting on semirings and the algebraic theory of automata.

### Members of the working group:

| | |
|---|---|
| Sergei TUPAILO | Senior Researcher, PhD |
| Varmo VENE | Researcher, PhD |
| Rustam NOVIKOV | Technician, MSc student |
| Peep KÜNGAS | Engineer, MSc (until 2002) |

### In collaboration with

| | |
|---|---|
| Ralph Matthes | Ludwig Maximilians Univ. München, Germany |
| Gilles Barthe | INRIA Sophia Antipolis, France |
| Luis Pinto and José N. Oliveira | Univ. do Minho, Braga, Portugal |
| Thorsten Altenkirch | Univ. of Nottingham, UK |
| Alberto Pardo | Univ. de la Republica, Montevideo, Uruguay |
| Gerhard Jäger | Univ. Bern, Switzerland |
| Michael Rathjen | Univ. of Leeds, UK |
| Reinhard Wilhelm | Univ. des Saarlandes, Germany |
| Helmut Seidl | Univ. Trier, Germany |
| Jeremy Gibbons | Oxford University, UK |

## 2.1.2 COMPOSITIONAL SYNTHESIS AND REUSE OF PROGRAMS

Principal investigator: Jaan PENJAM

The goal of this research project is to develop further techniques for program construction based on Tyugu's computational models via combining structural program synthesis (deductive method) and complement it by new methods for probabilistic programming and stochastic optimization (inductive method).

Automatic knowledgebased program construction based on declarative description of ontology of a problem domain has been investigated. A common formal basis for representing semantics of computations both at the level close to hardware primitives, and at the level of software components was presented. This logic is expressive enough for describing, first, the structure of hierarchical configurations and, second, dataflow both at signal and object level. It is sufficiently efficient for synthesis of large configurations and algorithms from their highlevel specifications.

An algorithm for coding sequential programs by real numbers was developed together with a method of transforming a task for program synthesis (on a first-order computational model) into an optimisation problem. This is an inductive approach based on the idea to search for the optimal program from among all possible sequences of relations of the computational model using genetic programming techniques. Actually, the same computational models by Tyugu are used for specification of problem ontology that are utilised for knowledge representation in structural program synthesis (deductive approach). We believe that combining these two types of techniques might provide more general and effective procedures to automate software development. This would simulate human reasoning where deductive inference steps are interleaved with drawing conclusions from samples of experimental data.

A new architecture of the system for synthesising distributed programs for GRIDs was developed (Fig.1). This research is motivated by utilisation and developing further existing paradigms (program synthesis using intuitionistic propositional calculus, Java language etc.) by increasing their performance via parallel computing.

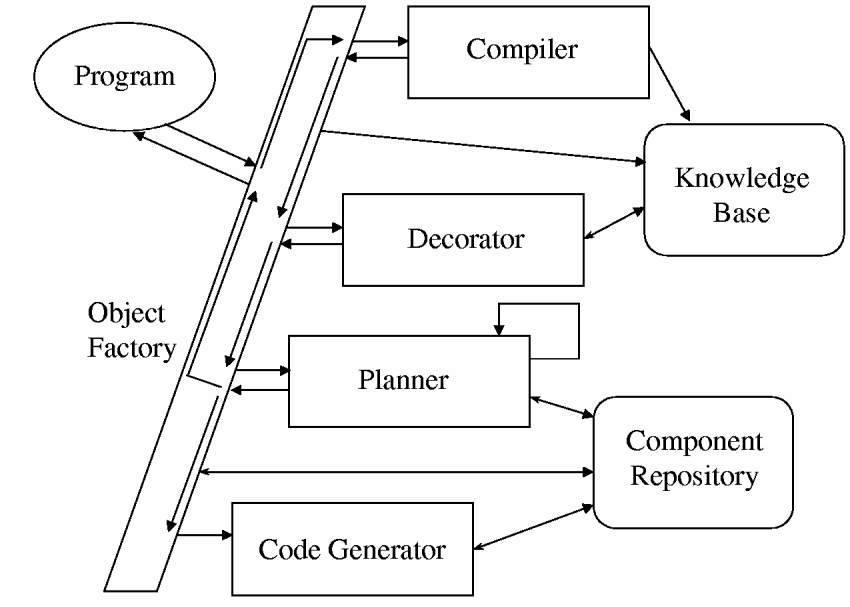



Figure 1. Modular structure of the distributed program synthesizer

Members of the working group:

| | |
|---|---|
| Enn TYUGU | Senior Researcher, DSc |
| Vahur KOTKAS | Researcher MSc |
| Ando SAABAS | Technician, MSC student |
| Jelena SANKO | Engineer, MSc |
| Mihhail SVINTSOV | Technician |

In collaboration with

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| Mihail Matskin | NTNU, Norway / KTH, Sweden |
| Grigori Mints | Stanford Univ., USA |
| Sven Lämmermann | IT Univ., KTH, Sweden |
| Vladimir Vlassov | KTH, Sweden |

### 2.1.3 CAD PROBLEM SOLVING AND TECHNICAL SYSTEMS MODELLING USING AI PROGRAMMING ENVIRONMENTS

Principal investigator: Ahto KALJA

A new conceptual design methods and a new software environment for mechanical engineering CAD have been developed. These methods include AI and visual programming principles. Experiments are here supported by special specifications languages and problem solvers.

Special new research projects for software process improvement related activities on a regional basis have been initiated. A comparison of software process assessment and improvement programs in Finland and Estonia has been performed. The prerequisites in a multi-organizational environment for successful software process assessment and improvement have been described.

Members of the working group:

| | |
|---|---|
| Mait HARF | Senior Researcher, PhD |
| Kristiina KINDEL | Engineer, MSc |
| Vahur KOTKAS | Project Manager, MSc |

In collaboration with

| | |
|---|---|
| Tiit Tiidemann | Tallinn College of Engineering |
| Marion Lepasaar | Tampere Univ. Technology /Tallinn Univ. Technology |
| Gunnar Grossscmidt | Tallinn Univ. Technology |

### 2.1.4 CONSTRUCTION OF DOMAIN ONTOLOGIES USING FCA

Principal investigator: Hele-Mai HAAV

The project aims to contribute to the development of methods for the automatic construction of application domain ontologies.

Our approach is based on automatic construction of domain-specific ontologies using Natural Language Processing (NLP) and FCA. The method constructs a formal concept lattice by algorithmic analysis of noun phrase patterns in domain-specific texts. Noun

phrases are extracted from the text by NLP tools. Resulting set of noun phrases is stored into the database table, which represents a context for the application domain in the form of binary relationship between domain-specific texts and noun phrases. FCA makes it possible to construct a formal concept lattice of the context. Formal concept lattice obtained is considered as formal domain ontology for given application domain. Architecture of the prototypical ontology design tool OntoDesign is developed. OntoDesign is a system for automatically constructing domain ontologies from given domain-specific texts by using FCA.

### Members of the working group:

| | |
|---|---|
| Boris Tamm | Senior Researcher, DSc |
| Kristiina KINDEL | Researcher, MSc |
| Kaili MÜÜRISEP | Postdoctoral Student, PhD |
| Tanel-Lauri LUBI | Student |

### In collaboration with

| | |
|---|---|
| Jørgen Fischer Nilsson | Technical Univ. of Denmark |
| Kuldar Taveter | TEKES, Finland |
| Margus Oja | Tallinn Univ. of Technology |

## 2.2 FORMAL METHODS FOR DESIGN AND ANALYSIS OF CONTROL SYSTEMS

### Principal investigator: Jüri VAIN

The goal of this research is to develop formal methods and tools for embedded and process control systems with focus on real-time constraints and hybrid dynamics. The research is carried out on the basis of hybrid (dynamical) systems theory, extended real-time logics, refinement calculi, compositional specification and verification methods. Main theoretical results are implemented in the integrated verification environment. The environment comprises tools for algorithmic (model checking) and deductive verification (1st and higher order theorem provers).

A component based modeling and verification technology for hybrid dynamical systems is developed. For CC- (control component) based hybrid system models the partial order reduction method is adjusted to accelerate CTL model checking. Finite abstraction technique for models representing degradation phenomena of non-stationary systems is proposed. Interactive model checking procedure integrating timed automata based model checking and 1st order theorem prover Gandalf is developed. A production line balancing method that combines global “branch-and-bound” approach with local “fine-grain” tunable model checking procedure is constructed. Analytical method for hierarchical structurization of homogeneous discrete systems is described and implemented.

Ongoing research areas

- formal methods for developing correct by constuction embedded software;
- adapting deductive and algorithmic verification methods for hybrid dynamical systems;

- tools supporting application of formal methods in industrial scale manufacturing and process control systems;
- methods of optimal structurization of knowledge and systems.

Members of the working group:

| | |
|---|---|
| Juhan-Peep ERNITS | Researcher, MSc |
| Marko KÄÄRAMEES | Researcher, MSc |
| Ingmar RANDVEE | Senior Researcher, PhD |
| Tiit RIISMAA | Researcher, PhD |

In collaboration with

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|---|---|
| Henrik Iskov Christensen | KTH, Sweden |
| Katsuhisa Furuta | Tokyo Inst. of Technology / Tokyo Denki Univ., Japan |
| Michael Reichhardt Hansen | Technical Univ. of Denmark |

## 2.3 PHONETIC STUDIES OF ESTONIAN SOUND SYSTEM AND PROSODY

Principal investigators: Arvo Eek and Einar Meister

The goal of the phonetic-phonological studies is a systematic investigation of articulatory, acoustic and perceptual features of Estonian sound system and prosody using contemporary research tools and methods. The results of the studies will be compiled into the monographic issue "Estonian Phonetics", intended as a university-level textbook for students of linguistics and speech communication.

In recent years the research has been focused on acoustics and perception of quantity degrees read at different speech rates and under different contextual circumstances. The Estonian quantity degrees are phonological two-syllable prosodic units the distinct durational patterns of which are based on various combinations of duration ratios of foot-internal neighbouring phonemes. Changes in speech rate will cause changes in absolute duration of phonemes but the duration ratios of neighbouring phonemes, characteristic to quantity degrees, will remain stable. Speech rate can be determined at least within a syllable: as word-initial consonant does not participate in quantity opposition, the perception experiments show that changes in duration of a word-initial consonant result in changes of perceptual boundary between short and long monophthong.

The results of the perception experiments confirm that two syllables are necessary for the identification of quantity degrees. A two-level model of perception of quantity degrees has been proposed. On the first (syllable) level listeners are able to distinguish whether the following phoneme is shorter or longer than preceding phoneme, but listeners are not able to determine the quantity degree. The decision about quantity degree can be made only after the comparison of phoneme durations at syllabic boundary, i.e. on the second (foot) level of the perception process.

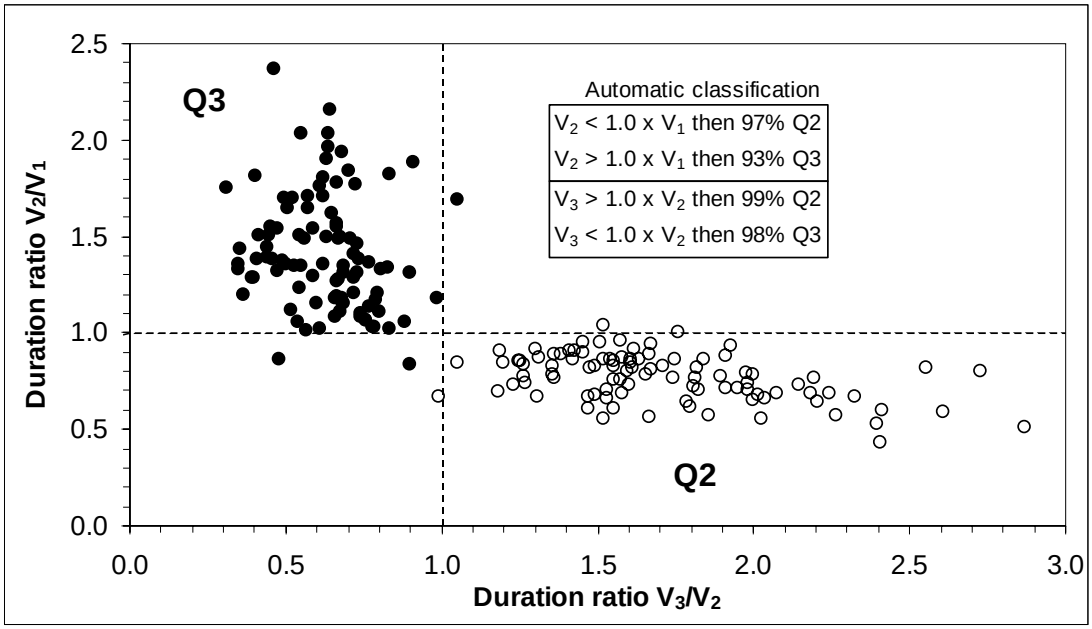


**Figure 2.** The words /lauta/, Q2 and /lau:ta/, Q3, read in fast, moderate and slow speech rate. Testing differences of quantity degrees on the basis of $V_2/V_1$ and $V_3/V_2$ (192 words, 4 speakers).

# 2.4 NONLINEAR WAVES

## 2.4.1 WAVE HIERARCHIES

Principal Investigator: Jüri ENGELBRECHT

The studies of wave hierarchies are aimed to analyse deformation waves in microstructured solids. The main idea is to find mathematical models, which are able to describe either only macrostructural behaviour or only microstructural behaviour or both, depending on the length scales of the microstructure and propagating waves. In mathematical terms such a wave motion is described by Whitham-type hierarchical evolution equations. Our earlier hypothesis in modelling was based on the concept of internal variables. This hypothesis was justified in case of soft tissues (Huxley-type models for cardiac muscles) and in case of materials where dissipation was important. However, if inertia of the microstructure is taken into account, then the concept of internal variables cannot be used any more. Such a case, for example, is the Mindlin-type microstructured material. It is shown that then dispersive effects are dominant. Contrary to usual approximations, the double dispersion (mixed derivatives) appears. The similar case is a granular medium (the Giovine-Oliveri model).

Main results of studies in 2000-2003 include:

- the derivation of the simplest model for describing wave hierarchies with dispersion and establishing its properties (J. Engelbrecht, F. Pastrone);
- numerical simulation of waves in microstructured (functionally graded) materials (A.Berezovski, J.Engelbrecht);

- numerical simulation of waves in dissipative materials using hierarchical evolution equations (T.Sillat, J.Engelbrecht);
- numerical analysis of the KdV-type hierarchical equations – the case of granular materials (A.Salupere, L.Ilison). The last case leads to soliton-type solutions (see Section 2.3.2).

Members of the working group:

| | |
|---|---|
| Arkadi BEREZOVSKI | Senior Researcher, PhD |
| Andrus SALUPERE | Senior Researcher, PhD |
| Lauri ILISON | MSc student |
| Tarvo SILLAT | MSc student |

In collaboration with:

| | |
|---|---|
| Franco Pastrone | University of Turin, Italy |

## 2.4.2 SOLITON DYNAMICS

Principal investigator: Andrus SALUPERE

Wave propagation in nonlinear dispersive media is studied. KdV-type evolution equations are used as model equations. Main attention is paid to formation, propagation and interaction of solitons and their ensembles. Discrete Fourier transform based pseudospectral methods are used for numerical simulation of wave processes.

1) *Wave propagation in granular materials* is modelled making use the hierarchical KdV equation including two different KdV operators (see Section 2.3.1). Dispersion analysis is carried out and solution types are detected over wide range of dispersion parameters. It is found that in the case of harmonic initial condition two main solution types can be distinguished: (i) only the KdV-type train of solitons emerges and (ii) the KdV-type soliton ensemble and the train of nearly equal amplitude solitary waves emerge simultaneously. The train of nearly equal amplitude solitary waves can be suppressed or amplified depending on the values of material parameters.
2) *Wave propagation in microstructured solids.* The microstructure causes higher order nonlinear as well as dispersive effects. Corresponding KdV-type evolution equations include higher order nonlinear and dispersive terms (the fourth order elastic potential and the fifth order space derivative, for example). Furthermore, the character of dispersion can be normal as well as anomalous. In 2000–2003 the main attention was paid to the normal dispersion case. The behaviour of solutions is analysed over long time intervals and wide range of dispersion parameters. Solution types corresponding to different models are detected and compared. The recurrence and super-recurrence phenomena are examined making use the discrete spectral analysis.
3) *Long time behaviour of KdV soliton ensembles.* The behaviour of KdV soliton ensembles is studied over very long time intervals (longer than 100 recurrence times). It is shown that there exists a critical value for the dispersion parameter in the sense of super-recurrence — for the stronger dispersion the super-recurrence takes place, but for the weaker dispersion this is not evident.
4) *Wave propagation in nonconservative dispersive media.* The influence of amplitude dependent periodic external driven field to the formation of solitons is studied. The

forced KdV equation is used as a model equation. The driven (force) field is divided into four categories — weak, moderate, strong and dominating — depending on the character of the solutions and/or the number of solitons. In cases of weak, moderate and strong field the character of the solution is solitonic.

The results can be used for determination of material parameters from experiments, in detecting structural defects (nondestructive testing) and in design of microstructured details in mechanical engineering. The topic is related to the technology of materials, which is a key area in Estonian science and development strategy.

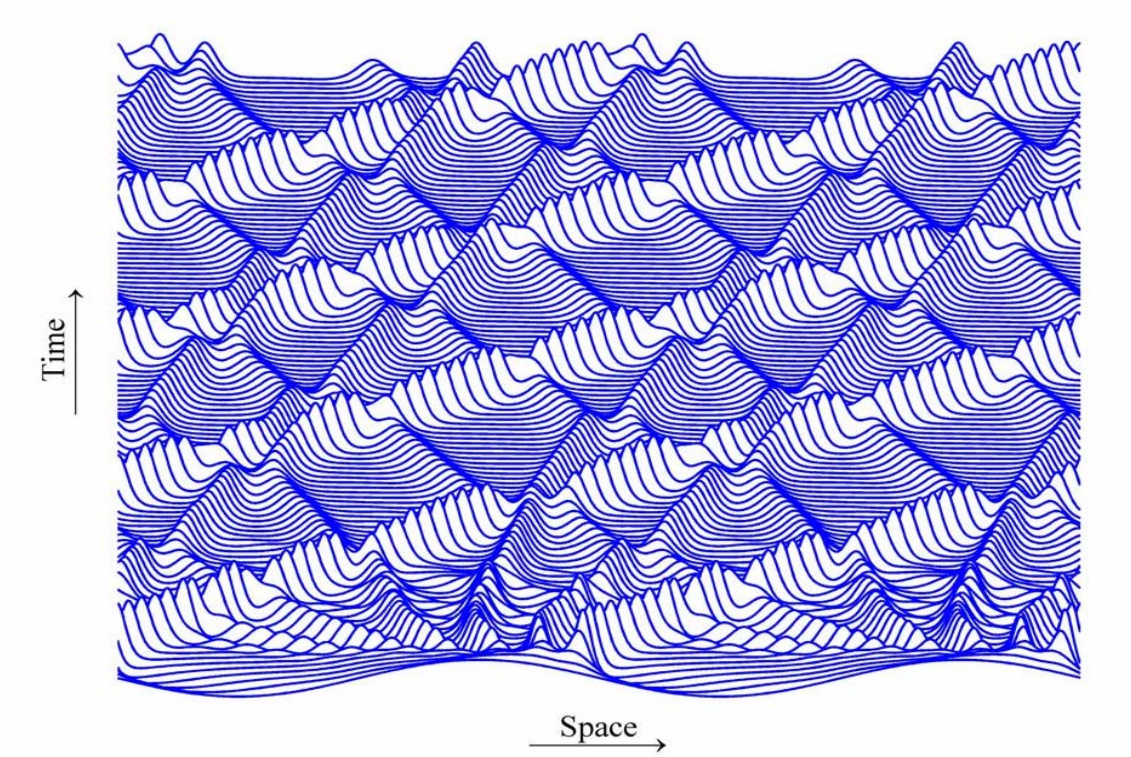


**Figure 3.** Formation of solitons from a harmonic excitation in force field. After a certain transfer period the emerging coherent pattern is seen with amplified solitons.

Members of the working group:

| | |
|---|---|
| Olari ILISON | PhD Student |
| Lauri ILISON | MSc Student |
| Mervi SEPP | Student |

In collaboration with:

| | |
|---|---|
| Gerard A. MAUGIN | Laboratoire de Modélisation en Mécanique, Université Pierre et Marie Curie, Paris 6, France |

## 2.4.3 SURFACE WAVES

Principal investigator: Pearu PETERSON, PhD

The fundamental question of soliton theory has been resolved for arbitrary number of solitons. The goal was to describe complicated “patterns”' formed by wave crests on the

surface of fluid which is natural environment for ships cruising at sea and is raising practical questions from hydrodynamic laboratories where waves are generated to test ships. To conclude - the interaction patterns of, say N, solitons can be reconstructed as the intersection between a moving two-dimensional hyperplane and the ridges set of a special N+1 dimensional polyhedron.

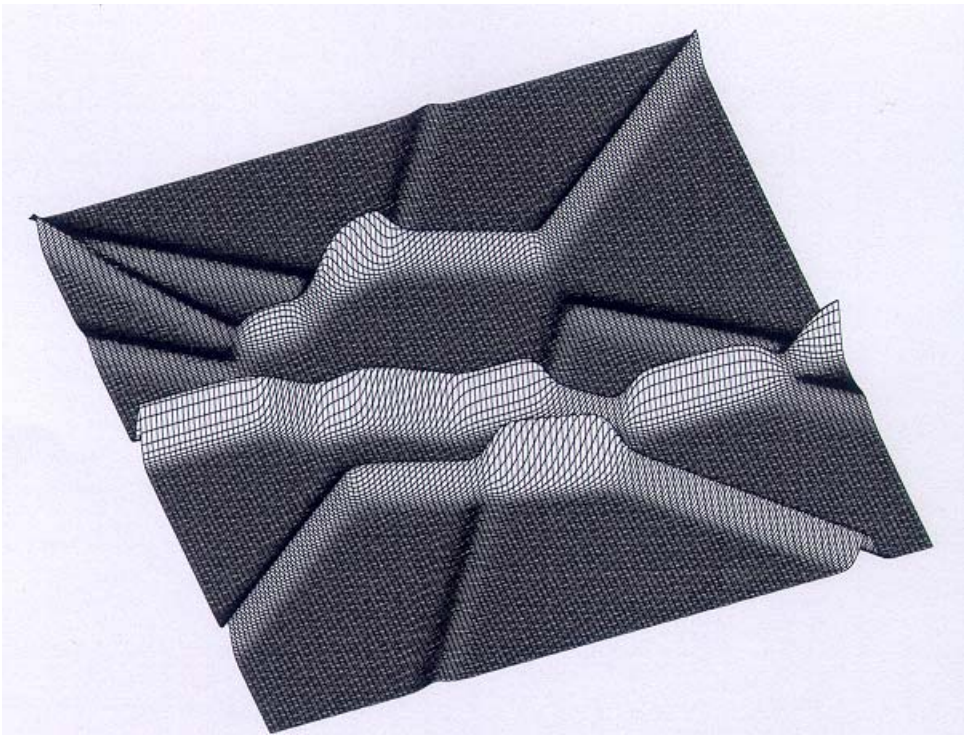

**Figure 4.** Interaction of five solitons

The exact numerical 2D free surface problem solver has been developed. The goal is to tackle the problem of deterministic generation of waves in hydrodynamic laboratories with the aim of producing non-breaking extreme (rogue or freak) waves. The soliton solution of finite background of the nonlinear Schrödinger model has been analyzed. The goal is to study the nonlinear Benjamin-Feir instability phenomenon as a possible mechanism causing extreme wave events.

In collaboration with:

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|---|---|
| Embrecht van GROESEN | Twente University, The Netherlands |
| Natanael KARJANTO | Twente University, The Netherlands |

## 2.4.4 ACOUSTODIAGNOSTICS OF INHOMOGENEOUS AND PRE-STRESSED SOLIDS

Principal investigator: Arvi RAVASOO

Utilization of nonlinear effects as an additional source of information in acoustic diagnostics is often embarrassed by the smallness of nonlinear effects. With the view to enlarge these effects, it was proposed to treat interaction of waves and to use the phenomenon of wave amplitude amplification by interaction in acoustic diagnostics.

Relatively simple ultrasonic methods for nondestructive evaluation (NDE) of (i) inhomogeneous prestress and (ii) weakly variable physical properties of the material (specimen, structural element, etc.) have been elaborated. The methods are based on utilization of nonlinear effects of simultaneous propagation, reflection and interaction of two ultrasonic waves in the material. The phenomenon of amplification of nonlinear effects by wave interaction is used.

The theoretical basis of both methods has been worked out. The corresponding analytical solutions have been derived. The solutions enable to follow evolution of ultrasound profile in the material and make it possible to determine the dependence of ultrasound profile distortion on the material properties and the prestress field parameters. It is clarified that the nonlinear effects that accompany two wave simultaneous propagation, reflection and interaction compose the main source of information for NDE of inhomogeneous prestress field and physical inhomogeneity in materials. By conventional methods, for example, by through transmission technique the nonlinear effects of ultrasonic wave propagation are small and there are problems to use them. Essential is that by the considered approach the wave interaction amplifies these effects and enhances the possibilities of NDE of material properties and states.

As an application, the algorithm for NDE of two-parametric plane inhomogeneous stress field (plane strain) in the material (structural element) with two parallel traction free boundaries has been presented. Two ultrasonic waves are excited simultaneously on opposite parallel boundaries of the material in terms of particle velocity. The propagation, reflection and interaction of waves are recorded on the same boundaries, but in terms of stress. Making use of the derived solution the linear part may be extracted from the recorded data and it may be used for NDE of linear physical properties of the material. The residue, the nonlinear effects that accompany two wave simultaneous propagation, reflection and interaction are sensitive to the prestress field parameters. An analysis of these effects in wave interaction interval enables to solve problems of qualitative and quantitative NDE of two-parametric plane inhomogeneous prestress field.

The second application deals with NDE of physical properties of weakly inhomogeneous nonlinear elastic material. It has been shown that for certain values of initial frequencies of simultaneously excited harmonic waves in inhomogeneous nonlinear elastic material the analysis may be simplified essentially. It becomes possible to derive the explicit analytical expressions for the amplitudes and phase shifts of harmonics. The result is that the material characterization algorithm can be formulated on the basis of harmonics amplitudes and phase shifts measurement data. This has been demonstrated on two model problems. In the first problem it is assumed that on the basis of the preliminary information the density of material of the specimens under investigation is constant but the linear and nonlinear elastic properties may deviate from the basic properties. The goal is to evaluate the real properties of each specimen on the basis of wave interaction data. In the second problem the preliminary information confirms that the inhomogeneous material has weak linear deviation of properties from their basic values. The basic values of material properties are assumed to be known and the inhomogeneity parameters must be evaluated. In both cases the NDE problem has been solved resorting to the plots wave characteristics versus material properties composed on the basis of the analytical solution.

The review of the elaborated yet nonlinear acoustodiagnostics methods for the nondestructive evaluation of variable in space and time properties of different materials has been published.

Members of the working group:

Andres BRAUNBRÜCK PhD Student

## 2.4.5 PHASE-TRANSITION FRONT PROPAGATION IN SOLIDS

Principal investigator: Arkadi BEREZOVSKI

A new approach to the modelling of the propagation of phase transformation fronts is proposed, which is founded on combining recent developments in material formulation of continuum mechanics, thermodynamics of discrete systems, and numerical methods for conservation laws. Special focus is placed on the initiation of phase transformation due to presence of stress waves.

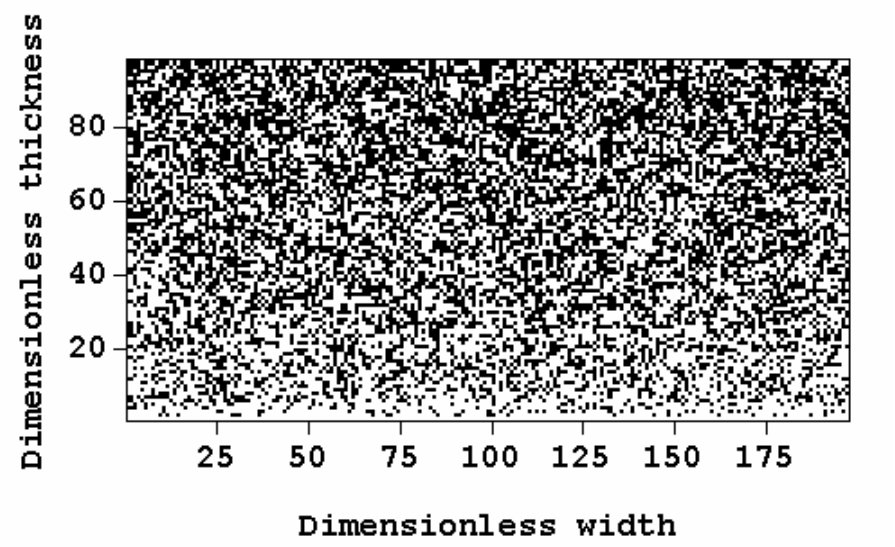


Figure 5. Random particle distribution in the modeling of a graded metal-ceramic composite.

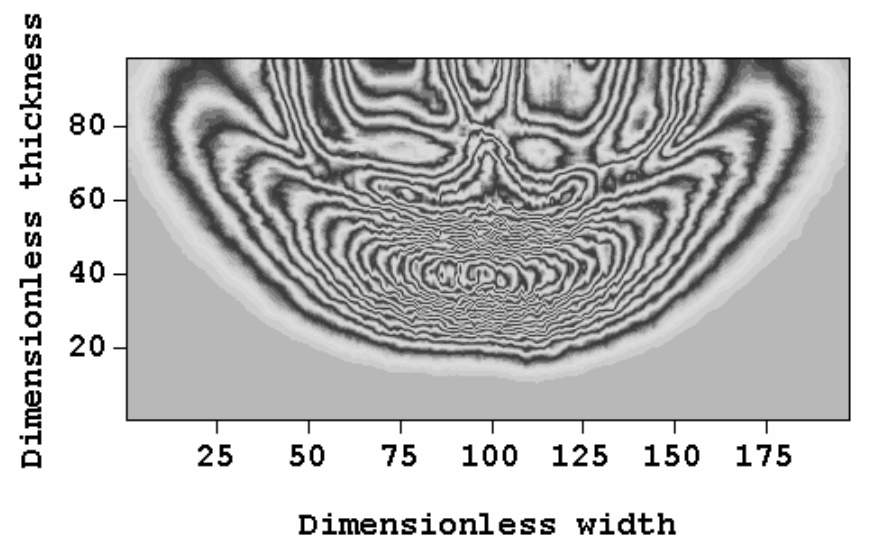


**Figure 6.** Wavefronts in the graded metal-ceramic composite with randomly embedded ceramic particles.

A stress-induced phase transformation in a thermoelastic solid is a strongly non-equilibrium process, because of a fast propagation of sharp interfaces through the material. Non-equilibrium thermodynamic conditions at the phase boundary are proposed to describe the propagation of phase-transition fronts in crystalline solids. A critical value of the driving force is determined that corresponds to the initiation of the phase transition process. A thermodynamically consistent form for the finite volume numerical method for thermoelastic wave and front propagation is developed. Such a reformulation provides the applicability of the Godunov type numerical schemes based on averages of field variables to the description of non-equilibrium situations.

The main results of studies in 2000-2003 include:

- derivation of a general three-dimensional description of phase boundary propagation in thermoelastic solids (A. Berezovski, G.A. Maugin).
- establishment of non-equilibrium thermodynamic consistency conditions at the phase boundary (A. Berezovski, G.A. Maugin).
- numerical simulations of impact-induced martensitic phase transition front propagation in Cu-Ni-Al shape-memory alloy (A. Berezovski, G.A. Maugin, T. Ugam).
- numerical simulations of two-dimensional thermoelastic wave propagation in media with rapidly-varying properties, e.g. in functionally graded materials (A. Berezovski, J. Engelbrecht, G.A. Maugin).

The research results make a basis for the development of a more detailed description of deformation waves propagation in microstructured solids.

Members of the working group:

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|---|---|
| Taavi UGAM | MSc Student |
| Jűri ENGELBRECHT | senior researcher, DSc |

In collaboration with:

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| Gerard A. MAUGIN | Laboratoire de Modélisation en Mécanique, Université Pierre et Marie Curie, Paris |

## 2.4.6 NONLINEAR HYSTERETIC MODELS OF PIANO HAMMER

Principal investigator: Anatoli STULOV

Based upon large number of experimental data obtained using a special piano hammer testing device that was developed and built in the Institute of Cybernetics at TUT, it has been shown that dynamical behavior of the piano hammer can be described by different mathematical hysteretic models. The first nonlinear hysteretic model of the piano hammer that is in a good agreement with experimental data, is the four-parameter model developed in 1995. This model is based on an assumption that the hammer felt made of wool is a microstructural material possessing history-dependent properties. Such a physical substance is called a material with memory. The second hysteretic model is a three-parameter model, very similar to nonlinear Voigt model and permits describe the dynamical hammer felt compression. This model is consistent with experiments too.

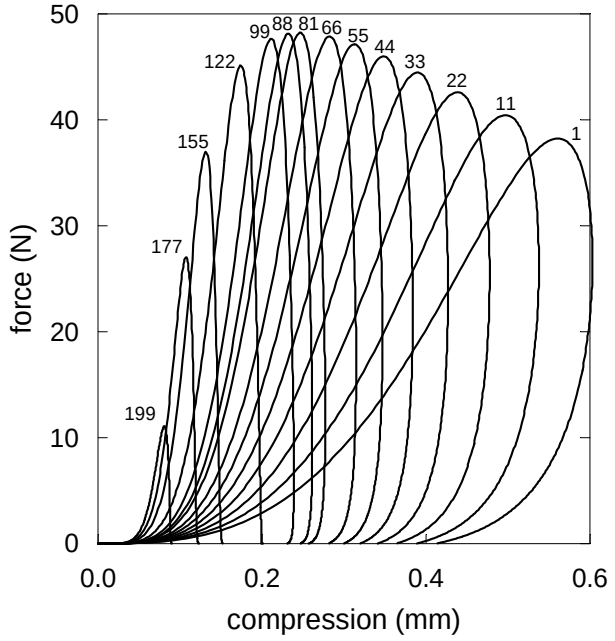


**Figure 7.** The simulation of the force-compression characteristics of piano hammers (the hammers N>88, are the *imaginary* hammers).

Both models are equivalent for the slow loading of the hammer. For the fast loading, these models give a different description of the hammer behavior. However, this difference can be observed only at an extremely high hammer velocity that is outside of the application range. Thus, both models can be used for simulation of the piano hammer-string interaction. The first model is based more on physical reasoning; the second model is simpler.

In collaboration with:

Avo MÄGI Tallinn Piano Factory, Estonia

# 2.5 FRACTALITY AND BIOPHYSICS

## 2.5.1 MATHEMATICAL MODELLING OF INTRACELLULAR ENERGY FLUXES

Principal investigator: Olav KONGAS, PhD

An integrated computer model for energy metabolism of the muscle cell was developed, focussing on how the energy transfer process regulates ATP synthesis in the mitochondria. Using the model, we designed experiments to resolve the long-debated issue: how high is the affinity of the respiration of heart mitochondria in situ to ADP? Experiments on skinned muscle fibres were performed by our collaborators at Free University Amsterdam and then analysed with our computer model, supporting the “high affinity hypothesis” and showing substantial diffusion gradients as the cause of previous misinterpretations. We have further successfully simulated the experimentally measured activation time of oxidative phosphorylation during quick transitions in ATP hydrolysis and its dependence on the level of creatine kinase (CK) activity. The results demonstrate the unique role of the particular CK isoenzymes: the cytosolic CK slows down the activation signal by

effectively buffering it whereas the mitochondrial CK controls the rate of the phosphocreatine shuttle; the activation time is determined by a nontrivial interplay between these two counteracting factors. Based on the modeling, we have designed experiments that should allow, for the first time, to determine the flux through the phosphocreatine shuttle in the heart.

Members of the working group:

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| Jüri ENGELBRECHT | Senior Researcher, DSc |
| Marko VENDELIN | Researcher, PhD |
| Maris LEMBA | MSc Student |

In collaboration with:

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| Valdur SAKS | National Inst. of Chemical Physics and Biophysics, Estonia |
| Johannes H.G.M. van BEEK | Free University Amsterdam, The Netherlands |
| Klaas KRAB | Free University Amsterdam, The Netherlands |

## 2.5.2 CARDIAC METABOLISM AND CONTRACTION IN HEALTH AND DISEASE

Principal investigator: Marko VENDLIN, PhD

ATP, a major energy carrier in cells, is synthesized in the mitochondrial matrix and its major use in muscle is for myofibrillar contraction and ion pumps. There is much debate on the mechanism of the regulation of the ATP synthesis in the mitochondria to balance ATP consumption during changing workloads. The model of transfer of energy-rich phosphoryl groups has also been disputed for decades. It turns out that the cell cannot be explained from knowledge of the behaviour of its constituent macromolecules in the test tube, i.e., the whole is greater than the sum of its molecular parts. Therefore, computer models are now considered necessary to understand the complex interplay of macromolecules in the cell. We have built a mathematical model consisting of three parts: production (OxPhos), transport, and consumption of the high-energy phosphates in myocytes. The model of biochemical reactions has been furnished with a spatial organization of the major intracellular structures resulting in a complex reaction-diffusion model of a working cardiac cell. Simulations with this model, validated against numerous experiments, have shed new light to compartmentation of the high-energy phosphates in both physiological and pathological conditions. An integration of the reaction-diffusion model of the cardiac cell metabolism into a 3D mechanical contraction model of a whole heart is in progress. Such a model will be suitable for studying the contraction of the ischemic or post-infarcted heart.

Members of the working group:

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| Jüri ENGELBRECHT | Senior Researcher, DSc |
| Maris LEMBA | MSc Student |

In collaboration with:

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| Valdur Saks | National Inst. of Chemical Physics and Biophysics, Estonia |
| Peter H.M. Bovendeerd | Eindhoven University of Technology, The Netherlands |
| Theo Arts | Eindhoven University of Technology, The Netherlands |
| Dick H. van Campen | Eindhoven University of Technology, The Netherlands |

## 2.5.3 STATISTICAL TOPOGRAPHY OF THE SYSTEMS AT SELF-ORGANIZED CRITICALITY (SOC)

Principal investigator: Jaan KALDA

For many systems at SOC, several important features of the system can be expressed in terms of random self-affine (or multi-affine) surfaces and self-similar (or multifractal) contour lines. Examples of such surfaces and lines include interfaces in various growth models, fracture surfaces, streamlines of turbulent flows, surfaces of geological landscapes, gradient-limited surfaces, iso-density lines of passively convected scalar, cloud perimeters, ripple wave turbulence etc. The statistical analysis of the geometrical properties of surfaces and contour lines is referred to as statistical topography. Our main results can be listed as follows. First, we have suggested a new efficient model for numerical analysis of such surfaces, the four-vertex (4V) model. Based on that model, we have calculated the fractal dimension of a single contour line as a function of the roughness exponent *H*. Second, we have suggested a new model for the evolution of geological landscapes, the model of gradient-limited surfaces. This model captures the most universal features of real landscapes (e.g. scale-dependence of differential roughness exponent, which increases towards smaller scales). Third, we have introduced a new object of analysis, the "coastline of oceanic islands"; we have shown that for negative roughness exponents, these coastlines are mapped to the percolation clusters of the correlated percolation problem.

## 2.5.4 ANALYSIS OF NONLINEAR TIME-SERIES

Principal investigator: Jaan KALDA

Non-stationary time-series are characteristic to a wide variety of processes, such as heart rate, electrical activity of brain (ECG), rainfall, geotectonic activity, financial time-series etc. Standard linear measures are far from being adequate tools for the analysis of these intermittent data. The methods based on non-linear deterministic models (e.g. correlation dimension) are neither appropriate. In particular we have revealed possible sources of false detection of deterministic chaos in heart rate signal. It is widely recognized that an appropriate approach to the analysis of non-stationary data is based on multifractal analysis. However, we have shown that even multifractal analysis is not sufficient for revealing all the features of such time series, the most important omission being the failure to describe long-term clustering of low-variability periods. To address this aspect, we have introduced the method based on multi-scaling Zipf's law describing the distribution of low-variability periods. We have shown that for heart rate variability, the measures based on this distribution law have a good diagnostic performance. We have also shown the relevance of this method to financial data.

Members of the working group:

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| Maksim SÄKKI | PhD Student |
| Robert KITT | PhD Student |

In collaboration with:

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| Mari LAAN | Nõmme Hospital, Estonia |
| Meelis VAINU | Tallinn Diagnostic Centre, Estonia |

# 2.6 NONLINEAR INTEGRATED PHOTOELASTICITY

Principal investigator: Hillar ABEN

The goal of research in the laboratory of photoelasticity is to widen the possibilities of integrated photoelasticity by non-destructive measurement of three-dimensional stress fields. The main application area of the results is residual stress measurement in various glass articles.

In the laboratory of photoelasticity a general optical theory of integrated photoelasticity has been developed using the quaternion formalism. This theory opens up the possibility to derive new equations for 3D photoelasticity. Theory of magnetophotoelasticity has been developed for the case of multiple reflections.

For stress measurement in step-index optical fibre performs a technology has been elaborated that takes into account the refraction of light. Classical sum rule has been generalized for the case of multilayered cylinders.

The method of photoelastic tomography in linear approximation has been elaborated for the measurement of 3D stress fields. Classical tomography is scalar field tomography where every point of the field is characterized by a scalar (e.g., the coefficient of extinction of the X-rays). In scalar field tomography, in the plane under investigation line integrals of the field in many directions (the Radon transform of the field) is measured and the field itself is determined with Radon inversion.

Radon inversion for the tensor field does not exist. The aim of the investigation was to decompose the problem of tensor field tomography into several problems of scalar field tomography for separate stress components. In the case when the optical birefringence is weak or rotation of the principal stress axes on the light rays is small it is possible to measure on every light ray the parameter of isoclinics, which determines the average direction of the principal stresses, and the integral optical retardation. These measurement results determine for every light ray two integrals of the components of the stress field. From these expressions it is possible, using the equilibrium equation, to derive an expression of the Radon transform for one component of the stress tensor. The normal stress distribution can be determined using Radon inversion.

Photoelastic tomography has been used for residual stress measurement in various glass articles (optical fibre performs of complicated cross-section, high-pressure electric lamps, bottoms of different bottles, etc.).

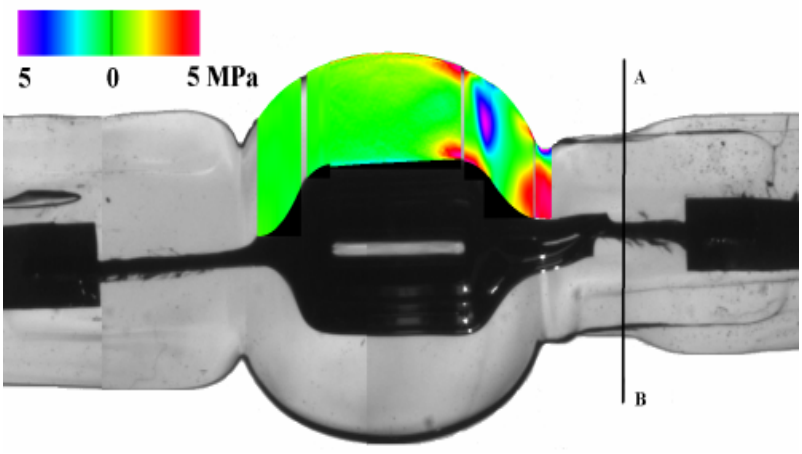


**Figure 8.** Geometry of the high-pressure lamp and axial stress field in the axisymmetric part.

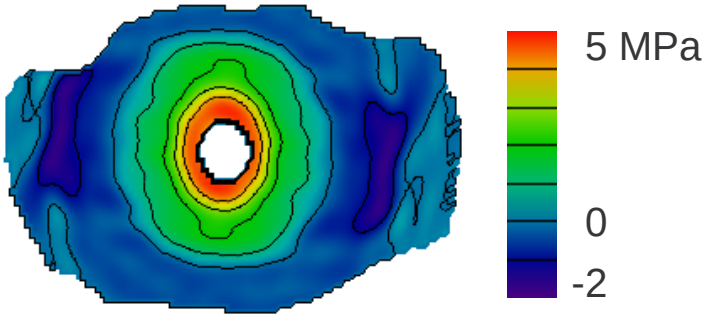


**Figure 9.** Normal stress field in section AB of the high-pressure lamp; 180 projections.

Members of the working group:

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| Leo AINOLA | Senior Researcher, DSc |
| Johan ANTON | PhD Student |
| Andrei ERRAPART | MSc Student |

## 2.7 APPROXIMATION FOR NONLINEAR MATHEMATICAL MODELS

The goal of this study is to obtain approximate solutions to certain problems of nonlinear mathematical modelling, in some cases to show the existence of an approximate solution, in other cases to give numerical methods with rates of convergence.

### 2.7.1 INVERSE AND ILL-POSED PROBLEMS

Principal investigator: Jaan JANNO

Inverse problems to determine space- and time-dependent kernels in partial differential equations have been studied. Such problems are related to the description of properties of non-homogeneous materials with memory. These problems have been studied in the case when the kernels are degenerate, i.e. they can be represented as finite sums of products of known space-dependent and unknown time-dependent functions. In some particular cases (e.g. when the material is piecewise homogeneous) the kernel is exactly degenerate. However, in general case, the degenerate kernel is an approximation of the exact kernel to be determined. Existence, uniqueness and stability of solutions of inverse problems to determine degenerate kernels in one-dimensional parabolic and hyperbolic equations have been proved under various boundary conditions and various types of observation. The results have been generalized to multi-dimensional hyperbolic scalar equations, too. The behaviour of the kernels has been discussed when the number of addends in their representation tends towards the infinity. These results imply uniqueness for the corresponding non-degenerate inverse problems in certain classes of smooth functions. Modified method of Lavrent'ev to regularize ill-posed operator equations has been studied. The method consists in solving a perturbated problem derived from the original one by means of adding an unbounded operator multiplied by a small parameter to the operator of the equation. For comparison: in the usual method of Lavrent'ev one uses the unity operator instead of the unbounded one. This modification has some advantages: higher qualification, the regularized solution has smaller oscillation, etc. Error estimates for the

modified method of Lavrent'ev have been derived both for the linear and nonlinear equations under the assumption that the degree of ill-posedness of the problem is not greater than one.

In collaboration with:

Lothar von WOLFERSDORF Freiberg University of Mining and Technology, Germany

## 2.7.2 APPROXIMATION OF PROBABILISTIC PROGRAMMING PROBLEMS AND INTEGRAL EQUATIONS

Principal investigator: Riho LEPP

Two types of stochastic programs with decision rules (solutions are discontinuous functions in reflexive Banach spaces of summable with p-th power functions) are approximated by sequences of finite dimensional problems with increasing dimension.

First one is the nonlinear quantile function minimization problem, second - an extremum problem with nonlinear integral functional and nonlinear probabilistic inequality constraints. In both cases the probability functional as an integral from discontinuous 0-1 Heaviside function is at first approximated by a continuous function in L-p metrics, $1 < p < \infty$, and then integrals are approximated by integral sums with increasing dimension. Conditions are presented, that guarantee stability of approximations both in optimal values and solutions. Also, the nonlinear Urõson integral equation with a discontinuous solution in L-infinity space of discontinuous measurable functions is approximated by integral sums with increasing dimension. Conditions are presented, that will guarantee stability of such an approximation.

## 2.7.3 WAVELET AND MULTI-RESOLUTION TYPE EXPANSIONS

Principal investigator: Jüri LIPPUS

The coefficients of wavelet and multiresolution-type expansions of functions with a given majorant of the modulus of continuity have been studied. The generalized Lipschitz classes of continuous functions are defined in the following way.

The main result in this direction is that the coefficient criteria of ordinary Lipschitz classes hold for a slightly larger class of majorants, namely those, satisfying the so-called Bari-Stechkin condition. This generalizes some results of Y. Meyer, S. Jaffard and M. Holschneider. Analogous problems in a slightly different context have been studied earlier, where some localized variants that take into account the behaviour of the function in a small neighbourhood of a given point have been proved. We have also constructed a counter-example showing that without the Bari-Stechkin condition these results do not hold.

The problem has its applications in signal and image processing, particularly in detecting edges while enhancing images. It is well known that in regions of slow change of the function its wavelet coefficients decay rapidly while in the regions where it changes rapidly, the speed of decrease of the coefficients is slow. Multi-resolution like schemes can also be applied in mapping to obtain smooth functions transforming maps made in one reference system to another reference system.

We have presented a multi-resolution like scheme for transforming maps made in different

reference systems. This result has been obtained in collaboration with the National Land Board.

In collaboration with:

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|---|---|
| Andi KIVINUKK | Tallinn Pedagogical University |
| Gert TAMBERG | Tallinn University of Technology |

### 2.7.4 NONLINEAR OPERATOR EQUATIONS

Principal investigator: Otu VAARMANN

Decisions making problems are frequently modelled by opimizing the value of an objective function under feasibility constraints. Typically optimization involves the problem of finding a fixed point for a mapping. For solving an operator equation F(x) = 0 (1), where F is sufficiently many times differentiable operator from a Banach space into another, a family of approximate methods with high order convergence is developed. Main difficulties of applied mathematical modelling lie in the fact that many essential models of science, technology and engineering are nonlinear and besides they may be ill-posed. For finding a generalized solution of (1) in Hilbert space setting iterative methods based on the use of weighted pseudoinverse are studied. If the range of F´ is not necessarily closed then iterative regularized methods based on the Gauss-Newton methods are developed for solving (1) and for finding stationary points of twice differentiable functional. Optimization under uncertainty was taken to consideration in the middle of the last century, however the existing experience leaves more questions than offers ready methods and ways for practical solution. Robust optimization and/ or multicriteria problems will be invsetigated later on. The robust optimization is itself important, but the method also permits parallelization on contemporary computers.

## 2.8 NONLINEAR AND ROBUST CONTROL

### 2.8.1 NONLINEAR CONTROL SYSTEMS

Principal investigator: Ülle KOTTA

The group research activities are directed towards developing theoretical and symbolic computation tools for modelling, analysis and synthesis of nonlinear control systems.

The group has made significant contributions in developing algebraic methods for discrete-time nonlinear control systems. The universal algebraic formalism has been developed that unifies the study of very different problems. In this formalism, the sequences of subspaces of the differential forms, associated to the control system are defined which contain a lot of information about the structural properties of the system. In the earlier years the problems of controllability and feedback linearization have been tackled within this formalism. During the last three years we investigated the use of algebraic methods for a number of fundamental properties of a control system, like system equivalence, irreducibility, reduction, and realizability in the classical state space form. Most procedures have been implemented in the computer algebra system *Mathematica*.

Our main effort has been devoted to development of tools and techniques to fill the gap between nonlinear system identification and controller design fields stemming from the use of non-complementary models, i.e. NARMA versus state space models, in those areas. First we have obtained the necessary and sufficient realizability conditions for NARMA

model in the classical state space forms as well the constructive procedure (up to finding the integrating factors) for constructing observable and accessible state space equations. We suggested a wide subclass of NARMA-models that admits a state space description, and studied the realizability properties of the bilinear i/o system, and associative system. We also have proved that the typical neural networks (NNs) based NARMA type model does not admit a classical state space description and suggested a new class that can be easily realized in the classical state space form, as well allows to simplify the controller design task in the i/o domain.

Second, we developed output feedback control laws directly for the i/o models. It is an alternative to be used when the nonlinear i/o model cannot be transformed in the state space form. The solutions for system linearization and decoupling info subsystems have been obtained. Advantages and limitations of the algebraic approach in comparison with other methods are also studied and clarified.

The group has strong international links as evidenced by the joint publications and in our active visitor program.

We plan to explore further and treat the other challenging problems within our formalism, including the realization problem for multi-input multi-output system. We plan to apply polynomial approach, which extends directly the results of the linear case to nonlinear domain. The basic difference is that unlike the linear case the polynomials related to the nonlinear system belong to a *non-commutative* polynomial ring that poses a number of open problems.

At present, not much application-oriented research is carried out in the group. As an intermediate solution, a nonlinear control system toolbox for computer aided modeling, analysis and synthesis of control systems on the basis of a computer algebra system *Mathematica* is being developed. With such a toolbox the prospective user is able to deal with more realistic problems. The future important activity is to make new contacts with industrial partners, through our present academic international co-operation, and also in Estonia.

### Members of the working group:

| | |
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| Sven NÕMM | Researcher, MSc |
| Tanel MULLARI | Researcher, MSc |
| Maris TÕNSO | Researcher, MSc |
| Eleri LAMP | Assistant |

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| Eduardo Aranda-Bricaire | CINVESTAV-IPN, Mexico |
| Alan Zinober | The University of Sheffield, UK |
| Nader Sadegh | Georgia Institute of Technology, Georgia |
| Jihong Wang | University of Liverpool, UK |
| Ronald K. Pearson | Tampere University of Technology, Finland |
| Ewa Pawluszewicz | Technical University of Bialystok, Poland |
| Fahmida Chowdhury | University of Louisiana at Lafayette, USA |

## 2.8.2 ROBUST CONTROL

Principal investigator: Ülo NURGES

A new approach to the robust stability analysis and to the robust controller design is proposed via reflection coefficients of discrete-time systems. The reason of using reflection coefficients instead of roots of the characteristic polynomial is that the mapping between reflection coefficients and polynomial coefficients is multilinear. So we can easily find some Schur stable line segments in the polynomial coefficient domain by varying a single reflection coefficient. The more serious task is: how to find a convex subset of the stability region in system parameters domain. Two possibilities are considered: first, the Schur stable polytope building around a given stable point and, second, determination of the stability radius of a given stable point. The first problem is solved starting from the discrete Kharitonov's theorem or from reflection vectors of a stable point. In order to solve the second problem via a simple search procedure the stability margin in direction of reflection vectors is introduced.

The robust controller design problem is formulated as a stability margin maximization task over the convex approximation of the stability region. This problem is solved by a quadratic programming approach.

Future research will focus on robust controller design via reflection vectors stability margin.

In collaboration with:

| | |
|---|---|
| Ennu RÜSTERN | Tallinn University of Technology |
| Rein LUUS | University of Toronto, Canada |

# 3 APPLIED RESEARCH AND DEVELOPMENT

Today the state and governmental institutions (ministries, state registers, larger municipal institutions etc.) and fiscal organisations are the only real customers that could be able to order scientific results from the institute. First of all, the organisations listed require development of information systems for management of their own structures. Some organisations order the analysis and prediction of the market situation for the services they are providing. A good example here is the studies of IoC mathematicians that have improved the tax system of the Estonian Traffic Insurance Foundation. The largest projects performed by IoC have been made on request of Ministry of Defence and Ministry of Communications and Transport to design radar based surveillance and control systems.

New private enterprises are as a rule small and not able to support applied research and development and use its results. The co-operation between IoC and local factories has a sporadic character. The joint research programme between Tallinn Piano Factory and IoC based on the results of research in the field of nonlinear wave propagation theory, that allows enhance the sound quality of grand pianos, is rather an exception.

IoC is the only institution in Estonia developing speech technology systems and carrying out studies in phonetics. Any kind of research in language technology that is related to Estonian specifics could actually be only done within the cultural environment and in the society actively using the language.

## 3.1 APPLIED RESEARCH PROJECTS

### 3.1.1 SIMULATION OF RADAR COVERAGE

Principal investigator: Vahur Kotkas

Radar technology is extensively used for surveillance of a territory in ecology, transport and logistics as well as in defence. Optimal dislocation and configuring of radars and other equipment of electronic surveillance is a complex problem, where a number of parameters should be taken into account. The geographic conditions evidently influence the effectiveness of a radar, as it “cannot see” any objects which are in the shadow of a big mountain, forest or building. In addition, a radar beam reflects from all the surrounding objects and depends on their physical properties like temperature, motion, vibration that change optical coefficients of reflection, refraction and absorption. Everybody has probably experienced the same difficulties when trying to see a small boat or a bird swimming in ripple, in particular, if it is a sunny day or evening. Electro-magnetic beams are also notably influenced by environmental conditions such as fog, rain, rising current of air. A radar antenna – a receiver – records reflections of radar beams from thousands of objects, but also waves produced by other senders, including cosmic radiation. To see just the needed objects on the radar screen, one must carefully choose equipment, data processing algorithms and configure their parameters.

To simplify this task, scientists have developed a new visual language for modelling surveillance systems, defined its syntax and semantics. “Writing” in this language is

similar to drawing on the geographic map of the territory to be surveyed. Every pixel of the displayed map is connected to the digital map of the region that defines geographic coordinates and altitude up from the sea level, type and height of vegetation, buildings etc. A user (designer of a surveillance system) can choose by mouse clicks different positions for dislocation of different equipment and determine their parameters, define hypothetic climate conditions and the objects should be followed by the system as a whole. Using these declarations and formal semantics of the language (ontology of the situation or surveillance scenario), the computer calculates the range where the system can detect the required objects. Results of the computations are visualized on the same map used for problem specification (Fig. 10.) that is easy and comprehensive for a designer to see the effectiveness of the system under development.

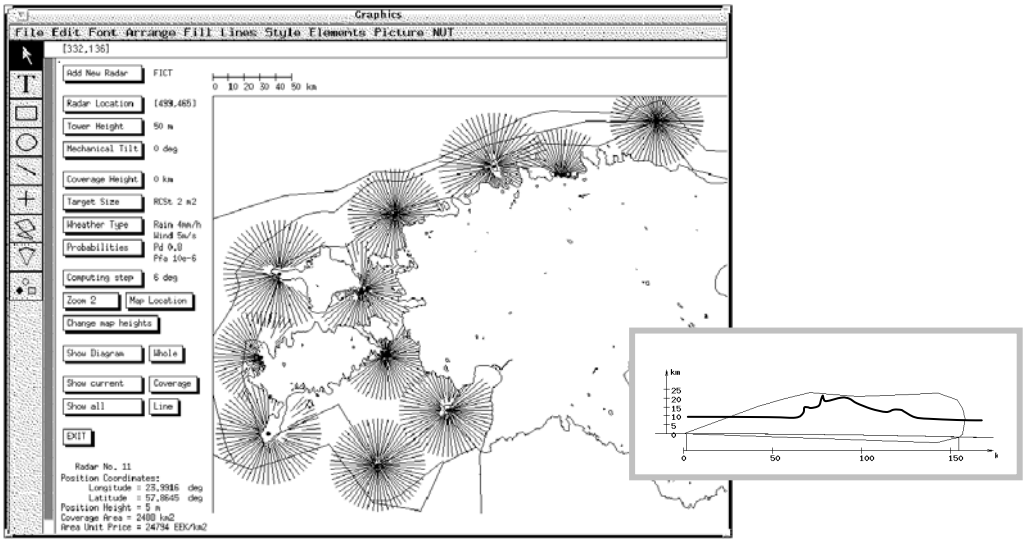


**Figure 10**. Radar coverage of costal area

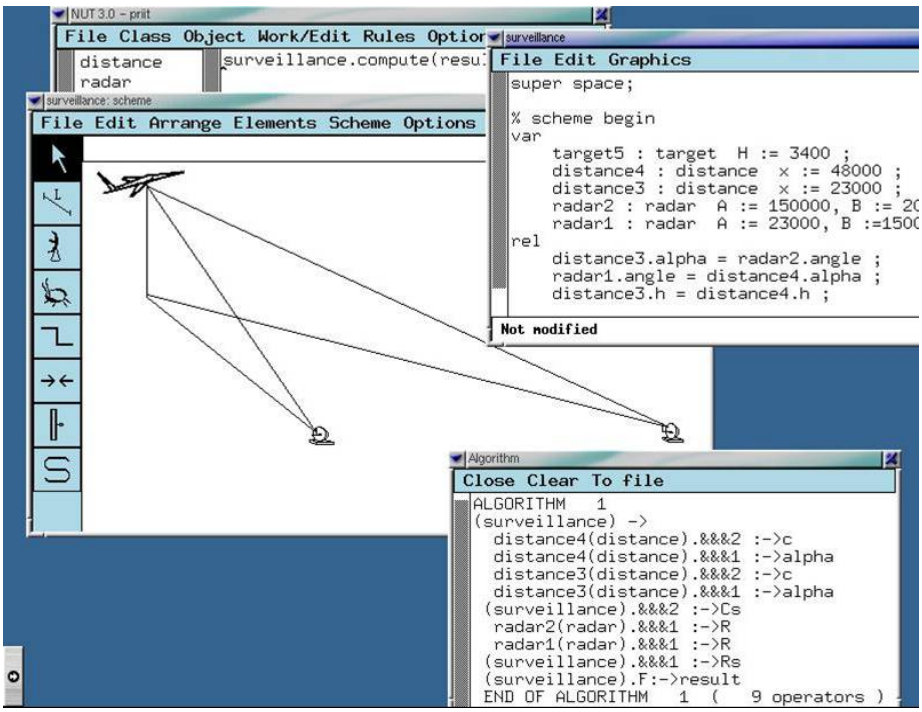


**Figure 11.** Adjusting radar parameters

One can click on particular radar that opens a new window with vertical radar coverage and relief of the ground (see a subwindow on the right side of Fig.10) that provides additional information about the reasons why the radar range has that certain value in the selected direction. The designer can move radars into different places or reconfigure them (Fig.11) and repeat computations until reaching a satisfactory solution.

The results of this study have been used by the Estonian Ministry of Defence and Estonian National Maritime Board for dislocation of their radar systems. The same language and computer system has been used to estimate mutual influence of the closely located radars and to establish the level of radiation of the environment by radars. The system could be easily extended with possibilities of using models of other electronic surveillance or communication devices.

## 3.1.2 SIMULATION OF HYDRAULIC SYSTEMS

Principal investigator: Ahto KALJA

This is one of the most successful applications of a visual language developed in cooperation with TUT. The unique results obtained by these researchers enable engineers to analyze very precisely dynamics of hydraulic systems and devices. Examples are analysis of hydraulic drives of robots and machine tools, hydraulics of landing gear of aircrafts, hydraulics of cars under the dynamic load. These systems are difficult to simulate because they belong to the so-called stiff systems that include both very high and very low frequency vibrations. Fortunately for engineers, the complexity is hidden in the semantics of the visual language, and it is hidden from the user. The language for describing a simulation problem looks like a conventional language of schemes known to engineers.

Visual communication and schemes as means of description are used also in mechanical design packages developed under the supervision of Ahto Kalja.

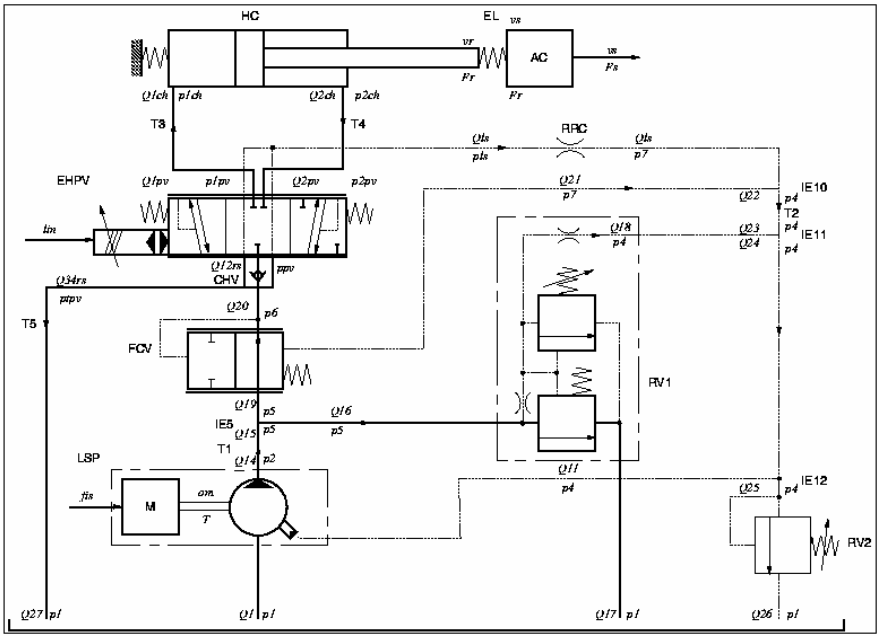


**Figure 12.** Load-sensing pump

Members of the working group:

Mait HARF Senior Researcher, PhD

In collaboration with:

Gunnar Grossschmidt Tallinn University of Technology

## 3.1.3 ESTONIAN TEXT-TO-SPEECH SYNTHESIS

Principal investigators: Einar Meister and Arvo Eek

The prototype of the Estonian TTS has been developed in cooperation with the Institute of Estonian Language and Filosoft Ltd.

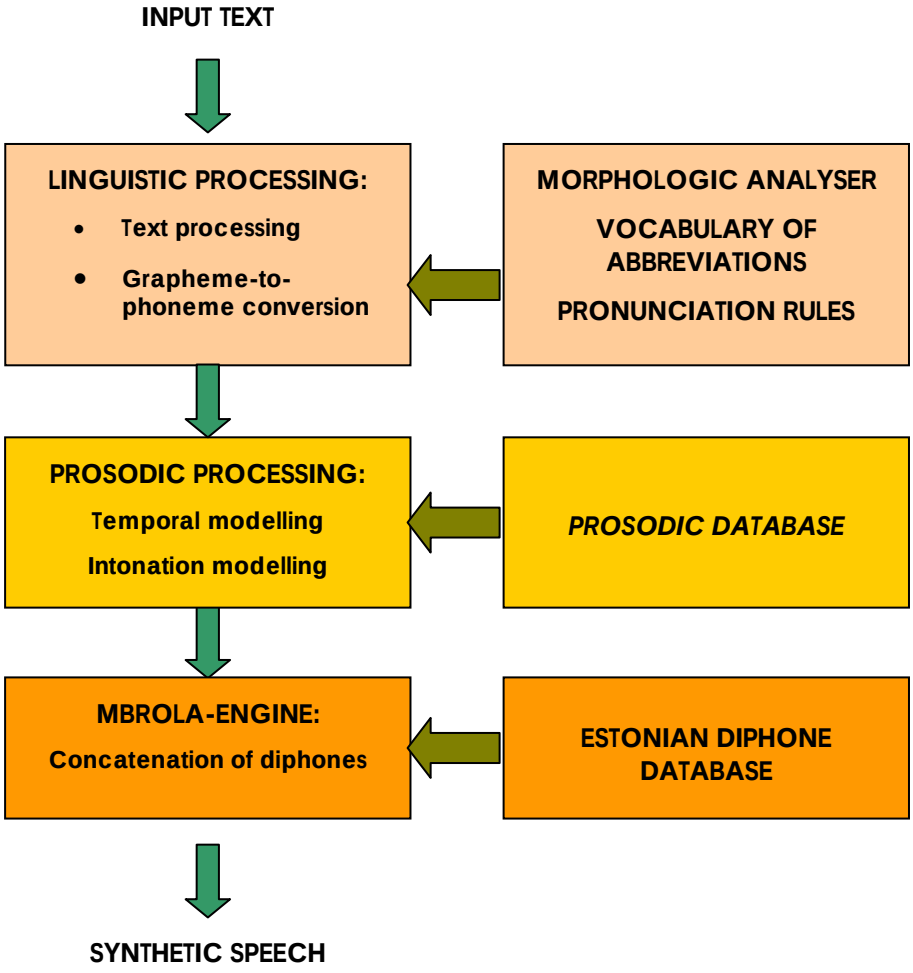


**Figure 13.** The structure of the Estonian TTS.

Within the EU Phare ACCESS project "Estonian Text-to-Speech Synthesizer for the Blind" (2002) the prototype has been developed further into software package compatible with MS Windows SAPI 4.0. The Estonian TTS software can be used by the blind together with several screen reader programs (e.g. JAWS, Zoomtext, etc).

The synthesis package has been made freely available for non-commercial and non-military use, and can be downloaded from http://www.phon.ioc.ee/synt/.

## 3.1.4 ESTONIAN SPEECHDAT-LIKE DATABASE

Principal investigators: Einar Meister, Jürgen Lasn, Lya Meister

A new database project was launched in 2002. It aims the collection of telephone speech from a large number of speakers for speech and speaker recognition purposes. At least 1500 speakers are expected to participate in recordings. Estonian SpeechDat has been designed to train several special-purpose speech recognizers, for example recognition of isolated command words, digit strings, numbers, dates and continuous speech, too. The possible applications include different voice driven teleservices accessible via fixed and cellular network. The specific sub-corpus for speaker verification includes speech items recorded by the same speakers at different time intervals. The Estonian database has been compiled according to SpeechDat (http://www.speechdat.org) design and formats.

Information about the number of registered speakers and successful calls is available on-line on the project's website (http://www.phon.ioc.ee/base).

## 3.1.5 DETERMINATION OF THE PIANO HAMMER PARAMETER

Principal investigator: Anatoli STULOV

Using a special piano hammer testing device that was developed and built in the Institute of Cybernetics at TUT, hundreds of different piano hammers were tested. It has been experimentally shown that a standard piano hammer possesses history-dependent properties, or just as well, it is made of a material with memory. It has been shown, that all the contemporary piano hammers have as a quality the hysteretic type of the force-compression characteristics. Such a hysteretic character is a result of a century of evolution and not a chance of uncommon hammers. The hereditary and elastic parameters of various hammers were obtained by numerical simulation of experimental data, using the nonlinear hysteretic models of piano hammer. Comparison of different piano hammers produced by various firms was carried out. It has been shown, that the hammers differ from each other mainly by their stiffness. It has been shown that the values of the hammer parameters do not depend on the diameter of the struck string. The quantitative estimation of the influence of the air humidity on the stability of the hammer parameters has been given. The quantitative and qualitative changes of the hammer parameters caused by the mechanical treatment (hammer *voicing*) of the piano hammer were demonstrated. The regular dependencies of the piano hammer parameters on the key number were derived.

The results obtained will be applied to the numerical simulation of the grand piano string vibration and the their spectra calculation. They will be useful for piano stringing-scale design and for the purpose of the technological process of the hammer manufacturing improvement. This project gives a possibility to improve the quality of grand pianos produced by Tallinn Piano Factory.

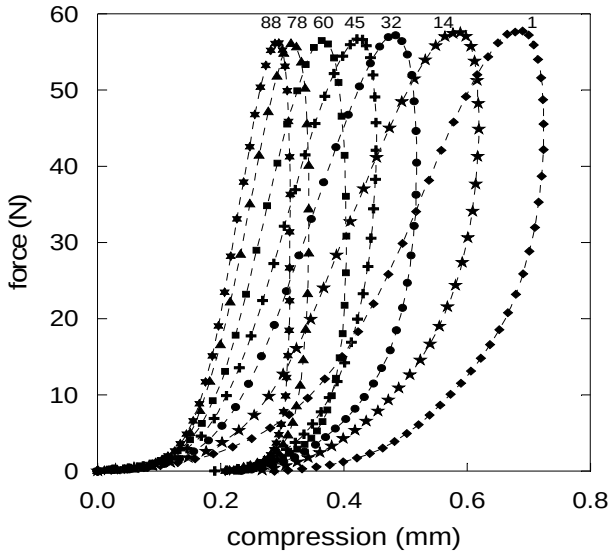


**Figure 14.** Experimentally measured the force-compression characteristics of Abel's hammer set.

In collaboration with:

Avo MÄGI Tallinn Piano Factory, Estonia

# 3.2 DEVELOPMENT PROJECTS

## 3.2.1 THE PROBABILISTIC AND STATISTICAL METHODS IN TRAFFIC INSURANCE

Principal investigator: Ivar PETERSEN

With the introduction of compulsory third party motor liability insurance in Estonia, the problem of tariff calculation from short-term statistical data arose. The Estonian Traffic Insurance Foundation, who is responsible for establishment of the motor insurance premiums, concluded a contract with the IoC to solve the corresponding theoretical and software problems. Different probabilistic and statistical models and methods were developed for the analyses and forecast of the frequency of road accidents, and for the amount at losses for different types of cars, and different regions of the country. For various reinsurance models (excess of loss, quota share, stop-loss, and their combinations) the premiums were calculated. The necessity to make motor insurance premiums dependent on drivers' age and sex was statistically proven. A method for calculating insurance premiums for contracts with self-retention was proposed. Through the traffic Insurance Foundation the results were regularly applied in Estonian insurance companies.

In the period 2000-2003 IoC continued to support the Estonian Traffic Foundation in tariff calculations for the compulsory third party motor liability insurance in Estonia. A software system was worked out and applied to realize special probabilistic and statistical algorithms for calculating insurance and reinsurance tariffs from short-term road accident losses data. Each year for different types of cars the expectations of next year loss amounts were predicted. The dependence of the frequency of losses on sex and age of the insured driver was investigated, and proposed as new tarification parameters. A method for calculating insurance premiums for contracts with self-retention was proposed.

Members of the working group:

| | |
|---|---|
| Klaus PUCK | Mathematician |
| Malle TUI | Technician |

## 3.2.2 NONLINEAR INTEGRATED PHOTOELASTICITY

Principal investigator: Hillar ABEN

An automatic polariscope AP-05 SM and relevant software have been elaborated for automatic stress measurement in solid and hollow axisymmetric glass products (drinking glasses, bottles, neck tubes of CRT bulbs, high pressure electric lamps, optical fibre preforms, etc.). A tomographic photoelastic method for the measurement of arbitrary three-dimensional stress fields, based on linear approximation, has been developed and implemented using the automatic polariscope AP-05 SM, supplied with a rotary stage for rotating the specimen. By tomographic photoelastic measurements the test object is turned with a stepper motor. Software of the polariscope controls tomographic photoelastic measurements and calculates the stress field using Radon inversion. The section under investigation is illuminated in many directions making photoelastic measurements on many light rays for every direction. While the classical tomography deals with the measurement of scalar fields, in photoelastic tomography we have to determine a tensor field. This complicated problem of tensor field tomography has been decomposed to several problems of scalar field tomography for separate components of the stress tensor.

**Figure 15.** Automatic polariscope

Members of the working group:

| | |
|---|---|
| Johan ANTON | Researcher, MSc |
| Andrei ERRAPART | Technician, BSc |

# 4 THESES

## 4.1 PROMOTED

**2000** **Varmo Vene** — PhD from University of Tartu. Title of thesis: "Categorical programming with inductive and coinductive types". Supervisor: **Merik Meriste.**

**Maris Tõnso** — MSc from Tallinn Pedagogical University. Title of dissertation: "Possibilities of symbolic computation in modelling of nonlinear control systems on the basis of *Mathematica*." Supervisor: **Ülle Kotta.**

**Jelena Sanko** — MSc from Tallinn University of Technology. Title of dissertation: "CAD software developing using AI techniques". Supervisor: **Ahto Kalja.**

**2001** **Pearu Peterson** — PhD from Tallinn University of Technology. Title of dissertation: "Multi-Soliton Interactions and the Inverse Problem of Wave Crests". Supervisors: **Jüri Engelbrecht** and Prof. Brenny van Groesen (Twente University).

**Marko Vendelin** — PhD from Tallinn University of Technology. Title of dissertation: "Cardiac Mechanoenergetics *in silico*". Supervisors: **Jüri Engelbrecht** and Dr. Peter H. M. Bovendeerd (Endhoven Technical University) and Prof. Valdur Saks (Joseph Fournier University/National Institute of Chemical Physics and Biophysics).

Alar Kuusik — PhD from Tallinn University of Technology. Title of dissertation: "Compact Smart House Systems: Design and Verification of Costeffective Hardware Solution". Supervisors: **Jüri Vain** and Prof. Mart Min.

**Kristiina Kindel** — MSc from Tallinn University of Technology. Title of dissertation: "Using Hybrid Software Systems for Creating Machine Design Software". Supervisor: **Ahto Kalja.**

**Andres Braunbrück** — MSc from Tallinn University of Technology. Title of dissertation: "Nonlinear Interaction of Longitudinal Waves in Inhomogeneous Elastic Material". Supervisor: **Arvi Ravasoo**.

**Olari Ilison** — MSc from Tallinn University of Technology. Title of dissertation: "Soliton Formation in Dispersive Media with Lower and Higher Order Nonlinearity". Supervisor: **Andrus Salupere**.

**Maksim Säkki** — MSc from Tallinn University of Technology. Title of dissertation: "On the Fractality of the Human Heart Rate Dynamics". Supervisor: **Jaan Kalda**.

Marion Lepasaar — MSc Title of dissertation: "Software Process Improvement in Small Software Organisations". Supervisor: **Ahto Kalja**.

2002 **Eo Feldmann** – MSc from Concordia International University in Estonia. Title of dissertation: "Forecasting Advertising Revenues. A Case Study of the Aripäev Publishing Ltd." Supervisor: **Ülle Kotta**.

**Juhan-Peep Ernits** — MSc from Tallinn University of Technology. Title of dissertation: "Model Checking Hybrid Systems". Supervisor: **Jüri Vain**.

**Peep Küngas —** MSc from Tallinn University of Technology. Title of dissertation: "Linear Logic Programming for AI Planning" Supervisor: **Tarmo Uustalu**.

**Taavi Ugam —** MSc from Tallinn University of Technology. Title of dissertation: "One-dimensional Numerical Modelling of the Stress-Induced Phase Transition Front Propagation in Shape memory Alloys" Supervisor: **Arkadi Berezovski**.

**2003 Einar Meister —** PhD from Tartu University. Title of dissertation: "Promoting Estonian Speech Technology: From Resources to Prototypes".

**Lauri Ilison —** MSc from Tallinn University of Technology. Title of dissertation: "Soliton-Type Waves in Granular Materials". Supervisor: **Andrus Salupere**.

**Maris Lemba** — MSc from Tallinn University of Technology. Title of dissertation: "Compartmention of Adenine Nucleotides in Cardiac Cell". Supervisor: **Marko Vendelin**.

## 4.2 THESES IN PROGRESS

### PHD

**Johan Anton** — Integrated photoelasticity in case of medium birefringence.

**Andres Braunbrück** — Nonlinear wave propagation in inhomogeneous solids.

**Juhan-Peep Ernits** — Application of formal methods in the analysis design and verification of embedded systems.

**Lauri Ilison** — Wave dynamics in hierarchical systems.

**Olari Ilison** — Soliton interactions in microstructured materials.

**Kristiina Kindel —** Distribute database and information systems.

**Robert Kitt** — Generalised scale invariance in financial time series.

**Vahur Kotkas** — Automated program synthesis in Java language.

**Marko Kääramees** — Technology for specification and verification of hybrid systems.

**Tanel Mullari** — The possibilities of application of second order connections in general relativity.

**Sven Nõmm**— Algebraic methods in nonlinear system theory.

**Jelena Sanko** — Inductive and deductive program synthesis methods.

**Maksim Säkki** — Long-range order and intermittance in biological signals.

**Maris Tõnso** — Symbolic computation tools for modelling, analysis and synthesis of nonlinear control systems.

**Taavi Ugam** — Modelling of the soundboard of grand piano.

### MSC

**Jekaterina Beloussova** — Evaluation of export perspectives of skimmed milk to Italy.

**Mihhail Berezovski** — Numerical simulation of elastic wave propagation in layered media.

**Andrei Errapart** — Photoelastic tomography for determining 3D state of stress in the case of weak birefringence.

**Rustam Novikov** — Multidimensionality in functional programming.

**Tanel Peets** — Wave propagation in nanostructured materials.

**Ando Saabas** — Visual specification languages.

**Mervi Sepp** — Influence of body forces on the formation of solitons in microstructured materials.

**Mihhal Svintsov** —Evolutional algorithms.

**Janek Tabun** — Identificability and identification of nonlinear control systems.

# 5 LIST OF PUBLICATIONS

All the publications from the period 2000–2003 are listed. Copies of the publications may be requested directly from the authors (the email addresses are included in Annex 8) – or, from Mrs. Marje Tamm, the Head of Library.

## 5.1 JOURNAL PAPERS

### 2000


1. **Aben, H., Ainola, L.** Isochromatic fringes in photoelasticity. – J. Optical Society of America. A, 2000, 17, 4, 750-755.
2. **Aben, H., Ainola, L.**, Anton, J. Integrated photoelasticity for nondestructive residual stress measurement in glass. – Optics and Lasers in Engineering, 2000, 33, 1, 49-64.
3. **Ainola, L., Aben, H.** Hybrid mechanics for axisymmetric thermoelasticity problems. – Journal of Thermal Stresses, 2000, 23, 685-697.
4. **Berezovski, A., Engelbrecht, J.**, Maugin, G.A. Thermoelastic wave propagation in inhomogeneous media. – Archive of Applied Mechanics, 2000, 70, 694-706.
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12. **Kalda, J.** Simple model of intermittent passive scalar turbulence. – Physical Review Letters, 2000, 84, 3, 471-474.
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19. **Randvee, I.** One-step memory closed-loop control of linear interconnected subsystems. – Proc. Estonian Acad. Sci. Phys. Math., 2000, 49, 2, 100-107.
20. **Ravasoo, A., Braunbrück, A.** Wave interaction for characterization of nonlinear elastic materials. – Proc. Estonian Acad. Sci. Eng., 2000, 6, 3, 171-185.
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22. **Stulov, A.**, Mägi, A. Piano hammer testing device. – Proc. Estonian Acad. Sci. Eng., 2000, 6, 4, 259-267.
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42. **Salupere, A., Engelbrecht, J.**, Maugin, G. A. Solitonic structures in KdV-based higher-order systems. – Wave Motion, 2001, 34, 1, 51-61.
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64. **Salupere, A., Peterson, P., Engelbrecht, J.** Long-time behaviour of soliton ensembles. Part I. Emergence of ensembles. – Chaos, Solitons & Fractals, 2002, 14, 9, 1413-1424.
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165. **Абен, Х., Айнола, Л., Антон, Д.** Применение интегральной фотоупругости для определения остаточных напряжений в стекле. - В: Развитие методов экспериментальной механики / Под ред. Н.А. Махутова, Б.Н. Ушакова, М.М. Гаденина. - М.: ИМАШ РАН, 2003, с. 24 - 39.

## 5.4 THESES

### 2001

1. **Peterson, P**. Multi-soliton interactions and the inverse problem of wave crests. Thesis of Tallinn University of Technology, Tallinn, TUT Press, 2001, 108, ISBN 9985-59-233-6
2. **Vendelin, M**. Cardiac mechanoenergetics *in silico.* Thesis of Tallinn University of Technology, Tallinn, TUT Press, 2001, 21. ISBM 9985-59-231-X

### 2003

3. **Meister, E.** Promoting Estonian speech technology: from resources to prototypes. - Tartu: Tartu University Press, 2003. - 216 p. - (Dissertationes linguisticae Universitatis Tartuensis, 1406-5657.

## 5.5 TEXTBOOKS AND HANDBOOKS

### 2000

1. **Littover, M., Lubi, L.** UML-keele sõnastik. – Tallinn: TTÜ Küberneetika Instituut, 2000. Elektroonne vers. http://www.cc.ioc.ee/uml/

### 2001

2. **Janno, J.** Variatsioonmeetodid. - Tallinn: Tallinna Tehnikaülikool. - 2001. 97 lk.

## 5.6 EDITED BOOKS AND SPECIAL ISSUES OF JOURNALS

### 2001

1. Wave Motion: Special issue on Nonlinear Waves in Solids: Analytical and Numerical Aspects / Maugin, G.A., **Engelbrecht, J.**, Samsonov, A. (eds). 2001, 34, 1.
2. Acoustic interactions with submerged elastic structures. Pt. II: Propagation, Ocean Acoustics and Scattering / Eds. A.Guran, G. Maugin, G., **J. Engelbrecht**, M. Werby. - Singapore [etc.]: World Scientific, 2001. 367 p. - (Series on stability, vibration and control of systems. Ser. B; 5).

### 2002

3. Databases and information systems. II: Fifth International Baltic conference "Baltic DB & IS'2002": Tallinn, Estonia, June 3-6, 2002: selected papers / Edited by **H.-M. Haav** and **A. Kalja.** - Dordrecht [etc.]: Kluwer, 2002. 331 p.
4. Databases and information systems. Vol. 1 and vol.2: Proceedings of the Fifth International Baltic Conference Baltic DB&IS 2002, Tallinn, Estonia, June 3-6, 2002 / [Institute of Cybernetics]; edited by **H.-M. Haav** and **A. Kalja.** - Tallinn: Tallinn University of Technology, 2002.

5. 14th Nordic Workshop on Programming Theory "NWPT 2002": Tallinn, Estonia, 20-22 November 2002: abstracts / [edited by **J. Vain** and **T. Uustalu**]. - Tallinn: Institute of Cybernetics at Tallinn University of Technology, 2002. 101 p.

### 2003

6. Proceedings of the Estonian Academy of Sciences. Physics. Mathematics: Special issue on nonlinear waves in microstructured solids / Guest editors **J. Engelbrecht, M.Kutser, G.A. Maugin.** 2003, **52**, 1.
7. Proceedings of the Estonian Academy of Sciences. Physics. Mathematics: Special issue on programming theory NWPT '02 / Guest editors **J. Vain, T. Uustalu,**- 2003, **52**, 4.
8. Nordic Journal of Computing. Special issue "Selected Papers of the Fourteenth Nordic Workshop on Programming Theory (NWPT'02), November 20-22, 2002, / Guest editors **M.Haveraaen** and **J.Vain,** 2003, **10**, 4

## 5.7 MISCELLANEOUS

### 2000

1. Küberneetika Instituut muutuvas ajas / [Toimetaja **M. Kutser**]. - Tallinn: TTÜ Küberneetika Instituut, 2000. 40 lk., ill.

# ANNEX 1. GRANTS FROM ESTONIAN SCIENCE FOUNDATION DURING 2000-2003

| No of grant | Title | Years | Principal investigator |
|---|---|---|---|
| 2772 | A concept-oriented approach for description and organisation of networked information sources. | 1997-2000 | H.-M. Haav |
| 3131 | Direct and inverse problems for acoustodiagnostics of materials. | 1998-2000 | J. Janno |
| 3137 | Algebraic methods in nonlinear control systems modelling. | 1998-2000 | Ü. Kotta |
| 3203 | Two-dimensional wave processes in continua with microstructure. | 1998-2000 | A. Stulov |
| 3204 | Mathematical modelling of intracellular energy fluxes. | 1998-2000 | J. Engelbrecht |
| 3595 | Methods of photoelasticity for non-destructive determination of 3D stress fields. | 1999-2001 | H. Aben |
| 3615 | Wavelets expansions and sampling series. | 1999-2001 | J. Lippus |
| 3616 | Approximate solution of nonlinear operator equations and extremum problems. | 1999-2001 | R. Lepp |
| 3737 | Optimal Structuring Methods of Decision-Making Systems in Informatics and Control. | 1999-2000 | I. Randvee |
| 3738 | Recursive control systems. | 1999-2002 | Ü. Kotta |
| 3739 | Self-consistent fractal modelling of the oxygen supply and contraction in myocardium. | 1999-2001 | J. Kalda |
| 4067 | CAD problem solving and technical systems modelling using AI programming environments | 2000-2003 | A. Kalja |
| 4068 | Interaction of solitary waves | 2000-2002 | A. Salupere |
| 4151 | Scale-invariance and intermittence in heart rate variability | 2000-2002 | J. Kalda |
| 4153 | Finno-Ugric prosody | 2000-2002 | E. Meister |
| 4154 | Speaker-specific feature in speech signals | 2000-2003 | E. Meister |
| 4155 | Intermediate and modal logics in programming language theory and formal methods | 2000-2002 | T. Uustalu |
| 4156 | Formal methods for verification of hybrid systems | 2000-2003 | J. Vain |
| 4497 | On the unity of proof theory | 2001 | S. Tupailo |
| 4504 | Propagation of phase-transition fronts in solids | 2001-2003 | A. Berezovski |
| 4704 | In silico studies of heart ischemie | 2001-2003 | J. Engelbrecht |
| 4705 | Methods for ontology design and ontology-driven search | 2001-2002 | H.-M. Haav |
| 4706 | Inverse problems for description of properties and states of inhomogeneous materials | 2001-2004 | J. Janno |
| 4707 | Algebraic methods in nonlinear control systems | 2001-2004 | Ü. Kotta |
| 4708 | Investigation of piano hammers | 2001-2002 | A. Stulov |
| 4718 | Estonian Winter School in Computer Science 2001 | 2001 | J. Penjam |

| | | | |
|---|---|---|---|
| 4972 | Nonlinear Integrated Photoelasticity | 2002-2005 | H. Aben |
| 5006 | Numerical analysis in modelling | 2002-2005 | O. Vaarmann |
| 5036 | Statistical topography for dynamical systems at self-organized criticality | 2002-2004 | J. Kalda |
| 5037 | Wavelet analysis and sampling series | 2002-2004 | J. Lippus |
| 5038 | Estonian Winter School in Computer Science 2002 | 2002 | J. Penjam |
| 5086 | Pattern-based modelling and analysis of computer integrated systems | 2002-2005 | T. Riismaa |
| 5400 | Extendable visual specification language and its supporting environment | 2003-2005 | E.Tõugu |
| 5405 | Nonlinear control systems: from theory through algorithms to program package | 2003-2006 | Ü.Kotta |
| 5565 | Wave dynamics and wave hierarchy in micro-strtuctured materials | 2003-2006 | A.Salupere |
| 5566 | Sound generation mechanisms in grand piano | 2003-2006 | A. Stulov |
| 5567 | Non-classical logics and programming theory | 2003-2006 | T.Uustalu |

# ANNEX 2. GRANTS FROM ESTONIAN INNOVATION FOUNDATION AND ESTAG DURING 2000-2003

| No of grant | Title | Years | Principal investigator |
|---|---|---|---|
| 683it/00 | Development of modelling environment for surveillance systems | 2000 | V. Kotkas |
| 3-6/60 | Competence Centre for Estonian Language Technologies (compiling of full proposal) | 2003 | E.Meister |

# ANNEX 3. INTERNATIONAL FUNDING

## FELLOWSHIPS

- Marie Curie Postdoctoral Fellowship, Free University, Amsterdam, Department of Physiology, Laboratory for Cardiovascular Research (O. Kongas)
- Post-doc in Minho University. Project PRAXIS XXI/X/EEI/14172/98 of Portugal Foundation of Science and Technology (T. Uustalu)
- European Language Resources Association (ELRA) for developing Estonian phonetic database (E. Meister)
- NATO linkage grant "Thermodynamics of progress and stability of phase interphases (crystals, alloys)", 2000-2001, University of Paris 6, France (A. Berezovski)
- French Foreign Ministery and Ministery of Sciences and Education scholarship for partial PhD studies in France, 1.10.2002-31.03.2003 (S. Nõmm)
- Marie Curie Postdoctoral Fellowship, University of Grenoble (M. Vendelin)
- Fulbright Scholarship for PhD studies, Washington University, Seattle, USA (M. Lemba)
- A. von Humboldt grant for research (2 months), University of Duisburg-Essen, Germany (J. Engelbrecht)

## PROJECTS

- Participation in the European Science Foundation Scientific programme "Nonlinear Acoustic Techniques for Micro-Scale Damage Diagnostics" (NATEMIS) (A. Ravasoo, 2000-2004).
- French-Estonian science and technology collaboration program PARROT.

## CONTRACTS

- Emhard Glass Research Inc. (USA) Contract for manufacturing and application of automatic polariscope AP-04 SM together with original sophisticated software (responsible scientist H. Aben).
- "Radar coverage modelling", Thomson-Airsys, France (responsible scientist V. Kotkas)
- "Automatic Photographing System", Curonia Research Ltd., Gibraltar (responsible scientist J. Vain).
- Philips (Netherlands) Contract for manufacturing and application of automatic polariscope AP-04 SM together with original sophisticated software (responsible scientist H. Aben).
- Pilkington (UK) Contract for manufacturing and application of automatic polariscope together with original sophisticated software (responsible scientist H. Aben).
- Cebrace (Brasil) Contract for manufacturing and application of automatic polariscope together with original sophisticated software (responsible scientist H. Aben).

# ANNEX 4. EDUCATIONAL AND OTHER SUPPORTING ACTIVITIES

## Selection of Regular Courses Prepared and/or Taught by the Personnel

### In Tallinn University of Technology

| | |
|---|---|
| Dynamics | A. Salupere |
| Statics | A. Salupere |
| Technical mechanics | A. Salupere |
| Theory of elasticity | A. Salupere |
| Continuum mechanics | A. Salupere |
| Mathematical modelling | J.Engelbrecht |
| Logic in computer science | J.Vain |
| Logical programming | J.Vain |
| Formal methods | J.Vain |
| Object-oriented programming | J.Vain |
| Theory and practice of computer graphics | J.Vain |
| Hybrid systems | J.Vain |
| Mathematical analysis I | J.Janno |
| Mathematical analysis II | J.Janno |
| Variational methods | J.Janno |
| Modelling and optimisation | Ü.Nurges |
| Computer Engineering | A.Kalja |
| Basics of Computer Aided-Design | A.Kalja |
| Software Project Management | A.Kalja |
| Theoretical computer science I | J.Penjam |
| Logic in computer science | T.Uustalu |
| Programming language semantics | T.Uustalu |
| Hybrid dynamical systems | J.-P.Ernits |
| Functional programming | V.Vene |
| Algorithms and data structures ITI | M.Kääramees |
| Adminstrating operating systems and computer networks | M.Kääramees |
| Algorithms of AI | E.Tõugu |
| Formal languages and compilers (Labs) | K.Kindel |

### In University of Tartu

| | |
|---|---|
| Functional programming | V.Vene |
| Semantics of programming languages | V.Vene |
| Models and calculi for software components | V.Vene |
| Methods of functional programming | V.Vene |
| Structure of operational systems | V.Vene |
| Programming languages | V.Vene |
| Introduction to speech communication | E.Meister |

### In Concordia International University in Estonia

| | |
|---|---|
| Probability and Statistics | Ü.Kotta |
| Management Statistics | Ü.Kotta |
| Computing essentials | V.Kotkas |
| Data communications and security | V.Kotkas |
| Management information systems | H.-M-Haav |
| Data and knowledge management | H.-M-Haav |
| Systems development basics | H.-M-Haav |
| Business calculus | J.Janno |

## Miscellaneous Courses

### In University of Messina (2000)

- Nonlinear evolution equations (PhD course)– J.Engelbrecht

### In University of Torino (2000)

- Nonlinear dynamics (PhD course) – J.Engelbrecht

### In Estonian Business School

- Statistics and probability theory (MSc course) – T.Riismaa

## Other Educational Activities of the Staff of IoC

J. Kalda, supervising the Estonian team of high school students for the International Physics Olympiad: 2000, Leicester, UK, (2 honours); 2001 Antalya (Turkey), (1 silver medal, 2 bronze medals); 2002, Bali, (2 bronze medals, 1 honours); 2003, Taipei (Taiwan) (1 silver medal, 1 honours).

# ANNEX 5. CONFERENCES ORGANIZED

## 2000

- "Glass Stress Summer School" was organized by Laboratory of Photoelasticity for engineers, technologists and scientists from glass industry and glass research laboratories to acquire contemporary photoelastic methods for residual stress measurement in glass products. The school contained lectures, equipment demonstrations, practical stress measurements and discussions. (Tallinn, Sep 12-15).
- The 5th Estonian Winter School in Computer Science (Palmse, Feb 27-Mar 2).

## 2001

- Lecture series "Spring Lectures in Mathematical Logic" (Apr-May). The purpose of this lecture series is to advance the research in mathematical logic in Estonia, as well as its application in various other branches in mathematics. The lectures were delivered by distinguished international experts in proof theory.
- The 6th Estonian Winter School in Computer Science, Palmse, Mar 4-9.

## 2002

- "2nd Glass Stress Summer School" Tallinn, Aug 14-16.
- The 14th Nordic Workshop on Programming Theory, NWPT'02, Tallinn, Nov 20-22.
- Colloquium Euromech 436 "Nonlinear waves in microstructured solids", Tallinn, May 29-Jun 1.
- Conference on Databases and Information Systems, Baltic DB & IS'2002, Tallinn, Jun 3-6.
- The 7th Estonian Winter School in Computer Science, Palmse, Mar 3-8.
- The XI Estonian Days of Mechanics, Tallinn, Sep 12-13.

## 2003

- 2nd Computer Science Theory Days, Arula Feb 3-5.
- "3rd Glass Stress Summer School" Tallinn, Jun 11-13.
- The 8th Estonian Winter School in Computer Science, Palmse, Mar 2-7.
- 3rd Computer Science Theory Days, Pedase, Oct 3-5.
- Advanced Study School "Nonlinear Processes in Marine Sciences, Hageri, Oct 12-19 (together with Marine Systems Institute at TUT).
- 2nd Estonian Summer School on Computer and Systems Science (ESSCASS'03), Taagepere Castle, Aug 10-14.

# ANNEX 6. AWARDS, PRIZES AND DISTINCTIONS

2000 – Jüri Engelbrecht

- Elected to the Bureau of IUTAM (International Union of Theoretical and Applied Mechanics) for the second term (2000-2004), to the Congress Committee for the third term and to the General Assembly.

2001 – Olari Ilison

- The student research award of the Estonian Academy of Science for his MSc thesis "Soliton Formation in Dispersive Media with Lower and Higher Order Nonlinearity".

2001 – Maris Tõnso

- The first research award of Tallinn Pedagogical University for her MSc thesis "The Possibilities of Symbolic Computation in Modelling of Control Systems with *Mathematica*".

2002 – Jaan Kalda

- Elected to the European Academy of Sciences and Arts.

2002 - Juhan-Peep Ernits

- The student research award of the Estonian Academy of Sciences for his MSc thesis "Model Checking Hybrid Systems".

2002 – Tarmo Uustalu

- Boris Tamm research award for young scientist.

2003 - Lauri Ilison

- The student research award of the Estonian Academy of Science for his MSc thesis "Soliton-Type Waves in Granular Materials".

2003 – Einar Meister and Arvo Eek (together with Meelis Mihkla and Heiki-Jaan Kaalep)

- Estonian Science Award in technical sciences for results in text-speech synthesis of Estonian language.

2003 – Sven Nõmm

- National student award for his paper "Realization of Interconnected Nonlinear Input-Output Discrete-Time Systems" in exact sciences.

2003 – Jüri Engelbrecht

- Chevalier, Palmes Academiques (France).

# ANNEX 7. BEST PUBLICATIONS OF THE YEAR

## 2000

- **Kalda, J.** Simple model of intermittent passive scalar turbulence. - Physical Reviw Letters, 2000, 84, 3, 471-474.
- **Peterson, P.,** van Groesen, E. A direct and inverse problem for wave crests modelled by interactions of two solitons. - Physica D. Nonlinear Phenomena, 2000, 141, 3-4, 316-332.

## 2001

- **Berezovski, A**., Maugin, G .A. Simulation of thermoelastic wave propagation by means of a composite wave-propagation algorithm. - Journal of Computational Physics, 2001, 168, 1, 249-264.
- **Ainola, L., Aben, H.** Transform equations in polarization optics of inhomogeneous birefringent media. - J. Opt. Soc. America, 2001, 18, 9, 2164-2170.
- **Janno, J.** Identification of weakly singular relaxation kernels in three-dimensional viscoelasticity. - J.Math. Anal. Appl., 2001, 262,1, 133-159.
- **Uustalu, T., Vene, V.,** Pardo, A. Recursion schemes from comonads. - Nordic J. of Computing, 2001, 8, 3, 366-390.

## 2002

- **Küngas, P.** Resource-conscious AI planning with conjunctions and disjunctions. - Acta Cybernetica, 2002, 15, 4, 601-620.
- **Lepp, R.** Approximation of the quantile minimization problem with decision rules. - Optimization Methods and Software, 2002, 17, 3, 505-522
- Pearson, R. K., **Kotta Ü., Nõmm S.** Systems with associative dynamics. - Kybernetika, 2002, 38, 5, 585-600.
- **Peterson, P.** Reconstruction of multi-soliton interactions using crest data for (2+1)-dimensional KdV type equations. - Physica D: Nonlinear Phenomena, 2002, 171, 4, 221-235.

# ANNEX 8. VISITING SCHOLARS

## 2000

Einar Broch JOHNSEN (Oslo University, Norway) – 5.01
Ellen MUNTHE-KAAS (Oslo University, Norway) – 5.01
Jaak VILO (European Bioinformatics Institute, United Kingdom) – 6.01
Dr. Ronald PEARSON (EHTZ, Zürich, Switzerland) – 26.02-4.03
Dr. Andras SZEKERES (Technical University of Budapest, Hungary) – 11.05-25.05
Lazlo E. KOLLAR (Technical University of Budapest, Hungary) – 30.06
Dr. Ewa PAWLUSZEWICZ (Technical University of Bialystok, Poland) – 15.08-10.11
Elena TROUBITSYNA (Abo Academi University, Finland) – 20.11

## 2001

Kenneth PEEBLES (NATO Research and Technology Agency) – 1.02
Dimitris SAMATOPOULOS (NATO Research and Technology Agency) – 1.02
Nils HOLME (Norwegian Defence Research Establishment, Norway) – 1.02
Dr. Ron PEARSON (EHTZ, Zürich, Switzerland) – 19.03-25.03
Prof. Alan ZINOBER (The University of Sheffield, United Kingdom) – 17.04-23.04
Dr. Peter BEDA (Technical University of Budapest, Hungary) – 23.04-29.04
Dr. Max SCHWEIZER (Gerbert Rüf Foundation) – 20.06
Dr. Richard BROGLE (Swiss Federal Institute of Technology, Zürich, Switzerland) – 20.06
Prof. Erkki K. M. LEPPÄVUORI (VTT Technical Research Centre of Finland) – 21.06
Lembit OSTRAT (Centre "EhitusTEST") – 21.06
Dr. Claude H. MOOG (Institut de Recherche en Communications et Cybernétique de Nantes, France) – 7.07-12.07
Dr. Romeo Ortega (LSS-Supelec, France) - 15.07-18.07
Dr. Andras SZEKERES (Technical University of Budapest, Hungary) - 20.08-09.09
Dr. Tiit KUTSER (Commonwealth Scientific and Industrial Research Organisation CSIRO, Australia) - 25.09
Prof. Pier Paolo DELSANTO (Polytechnic University Turin, Italy), - 03.10
Robert STEPIEN (Institute of Biocybernetics and Biomedical Technique of Polish Academy of Sciences) - 06.10
Prof. Brenny van GROESEN (Twente University, Netherlands) 07.11
Dr. Reinhard KAHLE (University of Tübingen and University of Munich, Germany), 09.04
Prof. Michael RATHJEN (University of Leeds, United Kingdom), 11.05.
Dr. ANTON SETZER (University of Uppsala, Sweden), 14.05
Prof. Grigori MINTS (Stanford University, USA), 25.05

## 2002

Prof. Heinz Peter GUMM (Philipps-Universität, Marburg) – 3.03-12.03
Prof. Juri MATIJASEVITŠ (Steklov Institut of Mathematics, St. Petersburg) – 3.03-8.03

Prof. Heikki MANNILA (Helsinki University of Technology/University of Helsinki) – 3.03-8.03
Prof. Helmut SCHWICHTENBERG (Ludwig-Maxmilians-Universität Munich) – 3.03-8.03
Prof. Alexander SCHILL (TU Dresden) – 4.03
Margus VEANES (Microsoft Research, Redmond, USA) - 11.03
Prof. Falk BARTELS (CWI, Amsterdam) – 12.03
Ralph MATTHES (Universität Munich) – 18.03
Dr. Andras SZEKERES (Technical University of Budapest, Hungary) – 1-6.04
Prof. Rolf JELTSCH (ETH Zürich) – 8.05
Prof. Yuri GUREVICH (Microsoft Research, Redmond, USA) - 12.07; 18.11
Dr. Ewa PAWLUSZEWICZ (Technical University of Bialystok, Poland) – 31.07-13.08
Dr. Jihong WANG (The University of Liverpool, United Kingdom) – 25.08-30.08
Prof. Roland BACHHOUSE (University of Nottingham) - 19.11
Dr. Adam EPPENDAHL (Queen Mary, University of London) - 25.11

## 2003

1. Dr. Neil GHANI (Leicester University) - 1-12.02
2. Prof. C.A. MOOG (Institut de Recherche en Communications et Cybernétique de Nantes, France) - 13-19.04.
3. Dr. Andras SZEKERES (Budapest Technological University) - 3-16.05
4. Prof. Gerard MAUGIN (Universite Pierre et Marie Curie) - 24-25.04
5. Dr. Gilles BARTHE (INRIA Sophia Antipolis) -11-18.05
6. Prof. D.BOULARAS (University of Limoges) - 2.05
7. Prof. Z. NAVICKAS (Kaunas Technological University) - 2.05
8. Dr. E. SCHNEIDER (Fraunhofer Institute for Nondestructive Testing, Saarbrücken, Germany) - 3.06
9. Dr Venanzio CAPRETTA (INRIA Sophia-Antipolis) - 27.08-6.09
10. Dr Thorsten ALTENKIRCH (University of Nottingham) - 7-18.09
11. Prof. Mati PENTUS (Moscow State University) 28.09-7.10
12. Prof Jaakko HOLLMEN (Helsinki Technical University) - 3-5.10
13. Dr. Neil GHANI (University of Leicester), - 17-23.11
14. Prof Luis PINTO (Minho University) - 2-13.12

# ANNEX 9. EMAIL ADRESSES

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