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Chair of Geometry, Tartu University
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Centre of Biomedical Engineering of Tallinn Technical University

CENS

Centre for Nonlinear Studies

Annual Report

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Lühikokkuvõte

Aastaaruanne sisaldab CENSi teadustöö lühikokkuvõtteid kõigis suundades, haarates järgnevaid probleeme: solitonide dünaamika, biofüüsika ja biomehaanika matemaatilised mudelid südame käitumise iseloomustamisel, super-korrelleeritud perkolatsioon ja geoloogiliste pindade moodustumine, mittehomogeensete ja eelpingestatud tahkiste akustodiagnostika, faasi-üleminekud, hüstereetiliste materjalide (klaverihaamrite) dünaamika, optiline mittelineaarsus, mittelineaarsete probleemide geomeetriline analüüs, lained vees (teoreetilised mudelid ja eksperimendid), mittelineaarsed filtrid elektroentsefalogrammide töötlemises, koherentne fotodetekteerimine mittelineaarses laserkeskkonnas. Lisaks on esitatud andmed finantseerimise, publikatsioonide, konverentsiettekannete, õppetöö jm kohta. Viimane osa aruandest sisaldab lühivaate tulevikule.

Abstract

The Annual Report gives a short overview in all the directions of CENS, including soliton dynamics, biophysics and biomechanics with the attention to cell energetics and heart rate variability, super-correlated percolation and formation of geological landscapes, acoustodiagnostics of inhomogeneous and prestressed solids, phase transition, dynamics of hysteretic materials with particular attention to piano hammers, optical nonlinearity, geometric approach to nonlinear problems, waves in fluids (both theoretical and experimental), nonlinear filtering techniques in monitoring electroencelophalograms, application of coherent photodetection in laser nonlinear active media. In addition, the data on funding, publications, presentations, teaching etc, are presented. The last Section gives a view ahead.

Keywords: nonlinear dynamics, cardiac contraction, cell energetics, solitons, acoustodiagnostics, photoelasticity, Rossby waves, symmetries of differential equations, signal processing.

1. Introduction

This Report is the second Annual Report of CENS. The year 2000 has been the year for consolidating research in several important directions. The annual meeting of CENS in March has approved the first Report 1999 and agreed upon activities for 2000 and further on.

Section 2 gives a short overview on CENS. In Section 3, the abstracts of all the studies are presented. This is the core part of the Report. Further on, the funding is described in Section 4 and the next Section 5 gives an overview on all the formal activities, such like published papers, conferences, lecture courses, etc. Section 6 is the summary including the further prospects for coming years.

2. Centre for Nonlinear Studies CENS

The structure of CENS in 2000 includes the following research groups:
Wave propagation (IoC at TTU);
Fractality and biophysics (IoC at TTU);
Optical nonlinearity (IoC at TTU);
Waves in fluids (Estonian Marine Institute);
Geometric approach (Chair of Geometry, Tartu University);
Biosignals (Centre of Biomedical Engineering of TTU).

The annual meeting of the Scientific Council (March 2000) has approved the activities and has agreed to continue the research in all the directions.

Many members of IAB have reacted positively on the Annual Report 1999.

The world of mechanics has lost a prominent member: Professor David G. Crighton has died in April 2000. CENS is mourning with all the community. The loss is even more because David was the member of the IAB. The Council of the Institute of Cybernetics has appointed a new member of the IAB in November 2000: Prof. Henry Keith Moffat, FRS (Cambridge, Isaac Newton Institute for Mathematical Sciences). The IAB of CENS has now the following members:

Prof.	Josef Ballmann (RWTH Aachen);
Prof.	Bengt Lundberg (Uppsala University);
Prof.	Gérard A. Maugin (University of Paris 6);
Prof.	H. Keith Moffat (Cambridge University);
Prof.	Valdur Saks (University of Grenoble);
Dr.	Andras Szekeres (Budapest Technical University);
Prof.	Dick van Campen (Eindhoven University of Technology);
Prof.	Erik van Groesen (Twente University).

3. Main results

3.1 Institute of Cybernetics, Tallinn Technical University.

3.1.1 Dynamics of microstructured materials and solitons.

Soliton dynamics in the framework of microstructured solids.
Wave propagation in microstructured (dispersive) media is studied. Harmonic initial excitation is used and the pseudospectral method is applied for numerical simulation of the wave propagation. Results are the following:

Solitary waves in periodically forced dispersive media. KdV-type nonlinear evolution equation with periodic force term in the r.h.s. is used to model nonconservative dispersive media. Single solitary waves or solitary wave groups are found to emerge from initial harmonic wave. Analysis of time evolution of these entities demonstrate that they behave like solitons. Dependences between dispersion-, force- and field parameters and solution types are found (A.Salupere, M.Kukk).
Solitary waves in media with higher order dispersion and higher order nonlinearity. KdV-type nonlinear evolution equation with fourth order elastic potential and both the third and the fifth order dispersion terms are used to model wave propagation in microstructured media. In this case, depending on signs of the third and the fifth order dispersion parameters, the dispersion can be normal or anomal. Here the normal dispersion case is studied. In the present case a train of negative solitons is found to emerge from a harmonic initial excitation. A domain in the dispersion parameters plane is detected where the solution behaves periodically. Dependences between dispersion parameters and number of solitons in the train are found (A.Salupere, O.Ilison).

Long time behavior of KdV solitons – weak dispersion limit
The long time behavior of the solitons of the standard KdV equation that emerge from a harmonic input is studied in order to understand the recurrence phenomenon first described by Zabusky & Kruskal. Criteria are found for determination of the soliton-soliton interaction type making use trajectories and time dependences of wave-profile maxima (A.Salupere, P.Peterson, J.Engelbrecht). In order to carry out long time integrations of the corresponding system a highly accurate and relatively fast numerical scheme is implemented (using FPIG, see below) that is based on finding the space derivatives using the FFT algorithm and using the Adams method for integrating in time. This method allows to lengthen the integration interval more than 100 times relative to classical cases and to consider cases with very weak dispersion (or very strong non-linearity). It is shown that (pseudo-)recurrences improve for the strong dispersion (weak non-linearity) cases in the long time observations. But for the weaker dispersion cases, this improvement becomes less frequent. A critical value (or interval) exists after which no recurrence improvement is observed. For a very weak dispersion no recurrence is observed at all. For the weak dispersion cases well-formed patterns in the soliton interaction pictures have been observed (P.Peterson, A.Salupere).

Software development
A program "FPIG – Fortran to Python Interface Generator" (http://cens.ioc.ee/projects/f2py2e/) is developed. Its purpose is to scan Fortran 77/90/95 codes and produce interface modules for Python language (http://www.python.org/) which allows users to call (computationally highly efficient) Fortran routines from (a very high level and flexible) Python language, and vice-versa (P.Peterson).

Surface solitons
The study of two-dimensional soliton interactions is continued in order to solve the inverse problem of wave crests. The inverse problem is about finding wave parameters (amplitudes + travelling directions) from the geometrical information of their interaction patterns. In the following waves are related to solitons.

As a result of this study multi-soliton solutions have been constructed for KdV type equations (in Hirota sense) using the Hirota bilinear formalism. A novel multi-soliton decomposition is proposed and analyzed. This decomposition is useful for describing the interactions between many solitons and it supports the following interpretation:

(i) when two solitons interact they emit the so-called *interaction soliton* that connects initial pure solitons and their shifted counterparts; (ii) in interactions with more than two solitons interaction solitons (from pairwise interactions of solitons) interact in the same way with third solitons (of any kind) emitting 'higher order' interaction solitons. The multi-soliton decomposition is just a superposition of all solitons and all possible interaction solitons.

This analysis has been carried out in phase variables showing that the decomposition has a clear geometrical meaning. If the results are projected to real variables (2D-space + time) then multi-soliton interaction patterns are in general non-stationary showing very complex interactions. With the results of this study these complex interactions are completely described and can be used to predict the evolution of non-stationary multi-soliton interaction patterns. For that an algorithmic method for constructing multi-soliton interaction pictures is derived (P.Peterson).

3.1.2 Biomechanics and biophysics

Mathematical modelling of intracellular energy fluxes

Recently the oxidative phosphorylation has been studied in chemically skinned cardiac cells. It has been shown that the affinity of such fibres with respect to ADP is ten times lower than that of isolated mitochondria. It has been supposed as a hypothesis that the "transparency" of the outer mitochondrial membranes was increased during the process of skinning. We have studied an alternative hypothesis which explains the lower affinity of fibres by restricted diffusion into them. It has been demonstrated by numerical simulations that the affinity of fibres may depend on the ratio of the velocity of synthesis of ATP in mitochondria to the activity of nonspecific background ATPaases. It is planned to check this hypothesis experimentally (O.Kongas).

Based on equilibrium thermodynamics, the activation mechanism of mitochondria in cardiac muscles at low working loads has been theoretically predicted (O.Kongas).

Mechanical contraction of the heart muscle.

We have analyzed the different kinetic schemes of creatine kinase and adenine nucleotide translocase complex interaction by comparing the simulation results with the available experimental data. The interaction between these enzymes plays an important role in overall energy transfer in cardiac muscle cell. According to results of our analysis, several schemes proposed in the literature earlier are not applicable. Namely, it is not possible to reproduce the creatine kinase reaction rate dependency on oxidative phosphorylation by assuming an existence of small "gap" between the enzymes or isolation of the enzymes from surroundings by outer mitochondrial membrane. Our preliminary results indicate that it is possible to reproduce the experimental data by assuming the existence of direct coupling between the enzymes. In the next year, we will focus on the development of the simple mathematical model which reproduces the measured properties of creatine kinase and adenine nucleotide translocase functional coupling (M.Vendelin).

We have analyzed the influence of the type of actomyosin complex interaction on the overall performance of the cardiac muscle. By comparing results of the experimental measurements and computations we've predicted some properties of the actomyosin complex. It is widely believed that the active stress formed in the muscle is a results of the cycling interaction of myosin heads with actin filament. The force produced by an attached cross-bridge is often assumed to depend linearly on the disposition along the myosin and actin filaments between the equilibrium position of the myosin head and the nearest actin binding site. Since the force exerted on the filament is determined by the first order derivative of the free energy function, the linear dependence of the force on disposition leads to a quadratic free energy function. In our study we modified the parabolic profile of the free energy function by taking into account the higher order terms (nonlinearities) of force. The effects of nonlinearities are studied by comparing the predictions of the model with experimental measurements of three type: (a) dependence of the cardiac muscle ATP consumption on a stress-strain area, i.e. the specific area in the stress-strain diagram; (b) the measured sarcomere length during a twitvh; (c) the developed peak isometric tension at different initial sarcomere lengths and the isotonic contraction traces at different afterloads and initial sarcomere lengths. We used a Huxley-type model for simulating the cross-bridge interaction and a phenomenological model of calcium-induced activation. The quantitative analysis allows to rule out some of the free energy profiles due to resulting non-physiological solutions. But there exists a wide range of actomyosin produced forces with linear or nonlinear shapes leading to acceptable solutions, choice is based on further experimental studies (M.Lemba, M.Vendelin).

In the next year, comparison of the rate constants experimentally measured in solution with the values found by optimization needs to be done. We also continue our work on development of 3D mathematical model of the left ventricular mechanoenergetics.

Fractality

Lattice representation of fractional Brownian surfaces, referred to as the *super-correlated percolation model*, has been developed. The model can be used as a universal and efficient tool for numerical simulations. It is a generalization of the two-dimensional percolation model and can be considered as the solid-on-solid model [H. Saleur et al, Phys. Rev. Lett. 58, 2325 (1987)] with positive roughness exponent H. The efficiency of the numerical applications has been demonstrated by calculating the fractal dimension D_h of contour loops. The simulation results support the idea that (1+1)-dimensional and real two-dimensional fractional Brownian surfaces belong to the same universality class. Furthermore, the excellent numerical efficiency of the model has been made it possible to determine the contour loop fractal dimension with very high precision; the results question the super-universality hypothesis of Kondev et al [Phys. Rev. Lett. 74, 4580 (1995)], which, if valid, would lead to the analytic dependence $D_h(H) = (3-H)/2$ (J.Kalda).

Heart rate variability

The analysis of the scale-invariant properties of the distribution of the low-variability periods of heart rate using large group (ca 200) of patients has been performed. It has been concluded that for healthy patients, the distribution typically follows multiscaling Zipf's law; for other groups of patients (with post myocardial infarction, hypertension etc.), the multiscaling behavior is less typical. The measures characterizing this multiscaling law can be used for diagnostic purposes (J.Kalda, M.Säkki).

Hierarchical internal variables

It has been shown how the formalism of internal variables can be generalized for cases when the microstructure has been described by several processes having a certain hierarchy. Such hierarchical internal variables stand in contrast to the case, when the microstructure is described by different scales. In the latter case the result is a hierarchy of waves (J.Engelbrecht, M.Vendelin).

3.1.3 General wave theory

Acoustodiagnostics of inhomogeneous and prestressed solids.
In acoustodiagnostics, the peculiarity of higher harmonic evolution and interaction caused by the simultaneous propagation of two longitudinal waves in nonlinear elastic material has been studied in detail. Three methods to use the algorithm that bases on the two wave interaction phenomenon in the nondestructive evaluation of the physical properties of the nonlinear elastic material are proposed: (i) the modified time-of-flight method, (ii) the reflected wave method and (iii) the two waves interaction method. All these methods make use of the wave velocity variation and wave profile nonlinear distortion data. The theoretical basis for description of two longitudinal waves simultaneous propagation in weakly inhomogeneous nonlinear elastic material is developed and the corresponding analytical solution is derived. The software Maple V enabled to derive the expressions sine wave propagation characteristics (harmonic's amplitudes, phase shifts) versus polynomial properties of the material for both, the wave propagation and the wave interaction intervals. The possibility to use these expressions in nondestructive characterization of material with variable in space properties is clarified on the basis of the numerical experiments. The review of the elaborated yet nonlinear acoustodiagnostics methods for the nondestructive evaluation of variable in space and time properties of different materials is composed (A.Ravasoo, A.Braunbrück).

Thermomechanics of complex systems
The cross-coupling in heat and moisture transfer is studied. The generalized models are proposed with certain relaxation times and diffusity given by corresponding matrices. Using the Onsager's reciprocity relations, the number of parameters is reduced to a minimum (J.Engelbrecht, A.Szekeres).

Thermodynamic model for phase-transition front propagation.
A thermomechanical description of coherent phase-transition front propagation in solids is developed. For this purpose, the material description of continuum mechanics is used with a full exploitation of the balance of pseudomomentum in order to establish the jump relations at the front and the expression for the driving force. The next step is the derivation of thermodynamic stability conditions for complex systems. These conditions are formulated by means of so-called contact quantities, which are introduced in the framework of the thermodynamics of discrete systems. The contact quantities are also used in the formulation of integral balance laws for discrete elements, which are applied for the construction of a finite-volume numerical scheme for thermoelastic wave propagation. Interrelations between bulk and contact quantities are established within the numerical scheme by means of a modified wave-propagation algorithm. As an example, a stress-induced martensitic-austenitic phase transition is simulated numerically in the one-dimensional case (A.Berezovski).

Piano hammer investigations
A piano hammer parameters measuring device was developed and built in the Institute of Cybernetics at TTU. This equipment gives a possibility to investigate the dynamical force-compression characteristics of piano hammer, and, using the hereditary (hysteretic) hammer model, to find the hammer parameters by numerical simulation of the dynamical experiments.

This device consists of three main parts. The first mechanical part gives the needed velocity of interaction of the hammer with the string. The second and the third parts are composed by a piezoelectric wide-band force sensor, and an infrared optical sensor for registration of hammer deformation. The analogue force-time and deformation-time signals from these two sensors are converted into two sets of data by a digital signal processor. Using these data, the force-compression characteristics of the hammer may be obtained for any hammer velocity.

In fact, the numerical simulation using the hysteretic hammer model may significantly simplify the process of the piano hammers manufacturing. The analysis of the hammer-string interaction shows that the nonlinear hysteretic model of piano hammer provides predictions about the vibration spectra of struck strings for real pianos that come closer to measured data, than predicts the nonhysteretic model. In addition to the correct spectra, the hysteretic model gives more suitable values of the hammer compression. The piano hammer parameters measuring device gives the possibility to find the dependencies of the hammer parameters on the key number. It seems that, for the one set of the good hammers such an explicit dependence exists. The numerical simulation of the known data shows that hereditary amplitude increases and relaxation time decreases definitely with a key number.

The hammer stiffness is a constant value in hysteretic model. This parameter depends on the hammer size, its wear, and on manufacturers. For one certain set of piano hammers it is possible to find the value of the instantaneous hammer stiffness experimentally. The knowledge of the hammer parameter dependencies on the key number permits to produce the hammers with the needed features (A.Stulov)

General problems

A simple scenario of the formation of geological landscapes has been suggested. It is summarized as follows. Inside a polygon, a random point and direction define the target line for the fault (elevation line). The fault divides the surface into two parts, one of which is elevated, and the other — lowered. The fault follows the aim line as closely as possible in such a way that after the elevation, the modulus of the local gradient remains everywhere below a threshold value. The process is repeated *ad infinitum*. The statistical properties of the resulting *gradient-limited surfaces* have been analyzed numerically using the super-correlated percolation model. A novel type of scale-invariant behavior has been predicted: the effective scale-dependent roughness exponent h is a decreasing function of the scale. At the intermediate range of scales, the result $h \approx 0.7$–0.9 is in a good agreement with the values recorded for geological landscapes. Intriguingly, the roughness exponents of the fracture surfaces vary in the same range (J.Kalda).

A new multifractal scalar field "harmfulness" quantifying the inhomogeneity of the passive scalar distribution in turbulent flow has been introduced. Assuming technological wastes perform the role of passive scalar, the "harmfulness" is the measure of the environmental damage. It is shown that in the case of passive scalar turbulence, both the multifractality of the "harmfulness" is caused by uneven stretching of fluid elements (J.Kalda).

Numerical algorithms.

A composite Lax-Wendroff-Godunov numerical scheme was developed for the modeling of thermoelastic wave propagation in rapidly-varying heterogeneous media on the basis of the wave-propagation algorithm. This algorithm combines high-resolution with multi-dimensional wave propagation. Every discontinuity in parameters is taken into account by solving the Riemann problem at each element interface. The reflection and transmission of waves at each interface are handled automatically. As a result, sharp resolution of shocks along with nearly second-order accuracy of smooth solutions is obtained. A number of simulations have been performed to estimate the correctness and capabilities of the algorithm, including: elastic wavefronts from point source at the boundary of a homogeneous medium; elastic wave propagation in a layered medium; elastic waves in a medium with periodically and randomly distributed inclusions; thermoelastic wave inside a medium with step-wise and continuously varying properties. All calculations were performed with the Courant number equal to 1. The standard numerical experiment with refining of the spatial grid shows that the refining of the grid gives more detailed distribution of computing parameters but does not change the qualitative results (A.Berezovski).

3.1.4 Optical nonlinearity and photoelasticity

The quaternion formalism has been used to derive new systems of equations that describe transformation of the polarization of light in inhomogeneous birefringent media. In quaternion algebra the problem of parametric representation of the unitary transformation matrix reduces to the problem of formulation of the quaternion in the trigonometric form. It is shown that it can be done in 30 different ways and that to each trigonometric form corresponds its own system of transformation equation equations. The two formerly known systems – the Neumann and Kuske equations – are among these systems. Some more complicated systems of the transformation equations are also presented. New transformation equations open up new possibilities for the analysis of the complicated optical phenomena which occur by passing polarized light through three-dimensional photoelastic models.

A tomographic method has been elaborated for the measurement of an axisymmetric birefringence field which is caused by an intense laser pulse in plasma. The cause of the birefringence is the Kerr effect. It is shown that parameters of the Gaussian distribution of the electric field can be determined by measuring integrated optical retardation only on two rays of the probe beam.

For obtaining higher precision by automatic measurement of the residual stresses in tempered glass articles, instead of the light intensity field the field of intensity gradient has been used. In the latter case interference fringes correspond to the points where the intensity gradient is zero. Due to that the location of the interference fringe between two pixels can be precisely determined using linear interpolation. The same algorithm is used for locating the boundaries of the specimen.

3.2 Tartu University

3.2.1 Geometric approach to nonlinear problems

The higher order cohomologies are studied for exterior calculus, in particular, the differential forms with $d^3 = 0$ on a free associative algebra and reduced quantum plane. For exterior differential their covariant generalization is given that restates the tensorial character of needed transforms (V.Abramov).

Lie calculus is used for describing the dynamical systems (M.Rahula). A science-popular essay "The Charm and Beanty of Mathematics" gives an overview for students about using geometry in description of abstract structures (M.Rahula).

3.3 Estonian Marine Institute

3.3.1 Waves in fluids

Theory of kinetic equations (resonant wave-wave interactions).
The equilibrium solutions to kinetic equations of weak turbulence (weakly nonlinear wave systems) are analysed in a systematic manner. The study is performed for kinetic equations involving any number of interacting waves of an arbitrary dimension. Conditions for the equilibrium solutions are reduced to generalised Cauchy functional equations defined at specific hyperfaces. Among differentiable functions, the formal equilibrium solutions correspond to equipartition of a linear combination of the energy, the components of the wave impulse and, optionally, the number of particles. The basic difference between interactions of sets of an odd and an even number of harmonics is that the number of particles does not enter into the equilibrium distribution in the former case. The most important consequence is that systems with four-wave resonance conserve the particle number (wave action) whereas systems with three-wave or five-wave resonance violate this law. Also, the set of equilibrium solutions to the kinetic equations basically depends on the number of interacting waves but not on wave type or dimension of wave systems. All the formal solutions notwithstanding their physical realisability are proved to be linearly stable with respect to small disturbances (T.Soomere).

Geophysical laboratory experiments.
Analysis of results of laboratory experiments with a cluster of closely packed vortices of like sign ("Coriolis" Laboratory of Geophysical Flows, on the rotating platform with the diameter 13 m, 1996) revealed amazing properties of persistence of certain monopolar structures and interactions between cyclones and anticyclones. Although isolated vortices of both sign had moderate standard and dynamical Rossby numbers, they nevertheless frequently exhibited strongly non-linear features and behaved like Petviashvili-type solitons. Details of vortex interactions (merging of vortices of like sign and forming of vortex dipoles) were not affected by apparent nonlinearity, soliton-like/isolated or geostrophically balanced/nonisolated nature of the counterparts provided the interacting vortices had a comparable size. In several experiments concentrated anticyclones demonstrated a bizarre tendency to penetrate into relatively large cyclones. The phenomenon resembled virtual locking of anticyclones in the central area of large geostrophically balanced cyclones, resulting in practically axisymmetric cyclonic structures with an oppositely rotating kernel. The process was asymmetric with respect to the vortex signs (T.Soomere, K.Rannat).

Wave-induced flows from turbulent boundary layers.
When a turbulent boundary layer is in immediate contact with the stably stratified free flow, turbulent disturbances at the interface result in radiation of internal gravity waves. The latter withdraw from the boundary layer turbulent kinetic energy, squared density (or buoyancy) fluctuations and other second-order moments. Wave-induced fluxes of these properties depend on the Brunt-Väisälä frequency in the free flow, N_0. As a result the boundary-layer turbulence becomes generally dependent on N_0. Zilitinkevich (2000) included this mechanism in a theoretical model of the boundary layer. In these type of models, both the fluxes of energy and buoyancy are needed. The wave-induced flux of energy is known to be proportional to N_0^3. It is traditionally supposed that this flux is insufficient for boundary-layer dynamics, as it usually plays a minor role in the turbulent kinetic energy budget. Here the flux of the density variance

(and consequently, the buoyancy variance) is shown to be proportional to N_0^5. This suggests that in strong stratification the effect of wave radiation on the boundary-layer turbulence could manifest itself much stronger through the budget of the buoyancy variance (T.Soomere, S.Zilitinkevich /Dept. of Meteorology, Uppsala University).

Turbulent processes, modelling of vertical structure of seas and sensor calibration theory

Set-up and stability criteria for numerical realisation of a model of vertical structure of thermohaline fields, caused by double diffusion effects, have been analysed in a systematic manner. The model contains three non-linear differential equations with variable structure for temperature, salinity and turbulent kinetic energy. The numerical realization of the model uses implicit difference method and the uniform rectangular time-space grid. The numerical stability criterion of the algorithm for the approximated solution is estimated (K.Rannat, P.Miidla, J.Heinloo).

An application of signal processing on the basis of Kalman filtering is constructed for an air space surveillance system. A new computational method known as the Fast Kalman Filtering provides effective statistical means for calibrating the whole system in real-time. Accuracy estimations based on the theory of Minimum Norm Quadratic Unbiased Estimation have been constructed in order to avoid any divergence of the filtering. The method can be easily generalized to any system of surveillance of extremal events (K.Rannat).

3.4 Biomedical Engineering Centre, Tallinn Technical University

3.4.1 Biosignals interpretations: Nonlinear filtering techniques in step detection of RMS EEG.

Monitoring EEG (electroencephalogram) during cardiac surgery to decrease the risk for brain deterioration is an active research area of many research groups nowadays. The problem is that EEG is a very complicated signal and during surgery there are many factors involved like anaesthesia and hypothermia. Extracting the changes in the signal due ischaemia from those due to other factors is complicated.

We had 51 recording of cardiac surgery available with two channels of EEG (C3-P3 and C4-P4), CVP (central venous pressure), SAP (systemic arterial pressure) and temperature. Our aim was to represent the data in a compact way to study the changes in signal behaviour in different phases of the surgery. EEG signal was compressed by calculating the RMS values of the 2 sec segments. By the visual inspection of the RMS curves we were surprised to find that they contained upward and downward step changes, which means that the energy of the signal changes abruptly at some time instances. It was considered important by neurophysiologists to detect these changes and have a warning in a monitoring system when such events occur.

The developed algorithm for the detection of the step changes in the RMS curve of the EEG signal contains non-linear median filtering. Alternatively, FMH (FIR Median Hybrid) filters can be used, however, in our experiment, median filter was found to work better. The "drawback" of the pure median filter to cause step-like behaviour is an advantage in our case because we wanted to enhance the step changes. After median filtering, the difference of the average of two sliding side windows was calculated and a step was detected whenever this difference exceeded certain predetermined value. Also, slopes were detected by line fitting and slope calculation of the median-filtered curve.

The developed algorithm was evaluated against visual scoring. The algorithm detected the events correctly in 70% of the cases. In addition, several events considered as slopes by the physician, were detected as steps and vice versa. The algorithm will be developed further and tested in a bedside monitoring setup. The scoring is not final yet, as the physiological meaning of the studied events needs further research. The study was made in tight co-operation with neurophysiologists from Royal Brompton Hospital and St. Bartholomew's Hospital, London (T.Lipping).

3.4.2 Application of coherent photodetection in laser nonlinear active media

Interaction of the electromagnetic waves inside the nonlinear active media of the lasers, or self-mixing, enables to use the same laser as a source of radiation and as a receiver simultaneously. A self-mixing coherent system with fibre-coupled laser diode, so called pigtail construction, will be more attractive, particularly because it is quite easy to be realised without any additional components. Such a Doppler optical coherent measurement system was developed for medical diagnostics. The pigtail laser at 1500 nm wavelength was used to measure the pulse wave delay and profile in different points of human body. The ECG perfomed as a reference signal for time delay measurements. The shape of the pulse wave was restored from the Doppler frequency swift caused by vibrations of vessel diameter. Useful information consists in the profile and velocity of the pulse wave. The laser device for cardiovascular diagnostics was exhibited at Hanover Mess in March 2000 (H.Hinrikus, K.Meigas, J.Lass, R.Kattai).

4. Funding

4.1 Basic funding through the Ministry of Education

4.2 Estonian grants:

1. ETF grant N 3131. "Direct and inverse problems of acoustodiagnostics".
2. ETF grant N 3203. "Two-dimensional wave in microstructured continua".
3. ETF grant N 3204. "Mathematical modelling of intracellular fluxes".
4. ETF grant N 3739. Fractal model of oxygen consumption and contraction in cardiac muscles".
5. ETF grant N 4068. "Interaction of solitary waves".
6. ETF grant N 4151. "Scale invariance and intermittency in heart rate variability".
7. ETF grant N4025. "Analysis and modelling of surface wave anomalies of the Baltic Sea".
8. ESF grant N 3411. "Electromagnetic Sensitivity of Biological Systems".
9. ESF grant N 4272. "Algorithms for Discrimination of Life-threatening Heart Arrhythmia".
10. ETF grant N 4281. "Application of Method for Optical Coherent Photodetection in Cardiovascular Diagnostics".
11. ETF grant N 3595. "Photoelastic methods for nondestructive measurement of stress fields".
12. ETF grant N 3308. "q-deformed Clifford algebras".
13. ETF grant N 4420. "Mappings and singularities in geometry and applications".

4.3 International grants

- NATO Collaborative Linkage Grant "Thermomechanics of progress and stability of phase interfaces (crystals, alloys)", partners University of Paris 6, Technical University Berlin.
- INSERM (France) grant "Modélisation biomathématique pour l'étude du métabolisme énergetique", partners University of Grenoble, University of Bordeaux.
- ESF Programme NATEMIS. "Nonlinear Acoustic Technique for Micro-Scale Damage Diagnostics", partners from many European centres in Italy, The Netherlands, Czech Republic, etc.
- EC Marie Curie Postdoctoral Fellowship to O.Kongas on Building Working Muscle Cells in the Computer: Biocomplexity and Metabolism" in Free University of Amsterdam.
- Dynamo (Dynamic Adaptive Modelling of the Human Body) project, Ragnar Granit Institute, Tampere University of Technology.

5. Publicity of Results

5.1 Research Reports

1.	Mech 217/00	J.Kalda, M.Säkki, M.Vaim, M.Laan. Heart rate variability.
2.	Mech 218/00	A.Ravasoo, A.Braunbrück. Wave interaction for characterization of nonlinear elastic materials.
3.	Mech 219/00	A.Berezovski, G.A.Maugin. A thermodynamic model for stress-induced phase-transmission front prapagation in thermoelastic solids.
4.	Mech 220/00	A.Stulov. Testing of piano hammers.
5.	Mech 221/00	A.Stulov. Piano hammer parameters measuring device calibration.
6.	Mech 222/00	A.Braunbrück, A.Ravasoo. Simulation of nonlinear wave interaction for elastic material properties evaluation.
7.	Estonian Marine Institute, 2000:	J.Elken, T.Soomere, J.Kask, T.Kõuts, U.Liiv, R.Perens, R.Rõõm. Hydrodynamical and geological studies of possible locations of Saaremaa (Ösel) deep harbour.

5.2 Publications

Papers (refereed)

1. J.Engelbrecht, A.Salupere, P.Peterson. Nonlinear wave motion: complexity and simplicity revisited. In: E.Lavendelis and M.Zakrzhevsky (eds.), IUTAM/IFT MM Symp. Synthesis of Nonlinear Dynamical Systems. Kluwer, Dordrecht, 2000, 25-36.

2. O.Kongas. A global map of local bifurcations. Ibid, 179-188.

3. A.Berezovski, G.A.Maugin. Thermoelasticity of inhomogeneous solids and finite-volume computations. In: B.Albers (ed.), Contributions to Continuum Theories, Anniversary volume for K.Wilmanski,Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Report N 18, 2000, 166-173.

4. A.Berezovski, J.Engelbrecht, G.A.Maugin. Two-dimensional thermoelastic wave propagation in inhomogeneous media. In: A.Bermudes et al. (eds.), Proc. 5th. Intern. Conf. on Mathematical and Numerical Aspects of Wave Propagation, SIAM, Philadelphia, 2000, 113-117.

5. P.Peterson, E. van Groesen. A direct and inverse problem for wave crests modelled by interactions of two solitons. Physica D 141, 2000, 316-332.

6. A.Salupere. Technique for detection of solitons in numerical experiments and virtual soliton. In: E.Oñate, G.Bugeda, G.Suárez (eds.) CD-ROM Proc. of the European Cong. on Computational Methods in Applied Sci. and Eng. - ECCOMAS 2000, 11-14 Sept., Barcelona, Spain, 17 p.

7. A.Ravasoo, A.Braunbrück. Wave interaction for characterization of nonlinear elastic materials. Proc. Estonian Acad. Sci. Engineering, 6, 3, 171-185.

8. A.Ravasoo. Nonlinear longitudinal waves interaction for inhomogeneously pre-deformed medium characterization. In: Nonlinear Acoustics at the Turn of the Millennium. ISNA-15. AIP Conference Proceeding. Melville, New York, 524, 337-340.

9. J.Kalda. Simple model of intermittent passive scalar turbulence. Phys. Rev. Lett. 84(3), 2000, 471-474.

10. J.Kalda. On the multifractal properties of passively convected scalar fields. In: Paradigms of Complexity. Fractals and structures in the sciences. M.Novak, ed. World Scientific, Singapore 2000, 193-201.

11. J.Engelbrecht, M.Vendelin, G.A.Maugin. Hierarchical internal variables reflecting microstructural properties: application to cardiac muscle contraction. J. Non-Equil. Thermodyn. 25(2), 2000, 119-130.

12. V.Saks, O.Kongas, M.Vendelin, L.Kay. Role of the creatine/phosphocreatine system in the regulation of mitochondrial respiration. Acta Physiol. Scand., 168(4), 2000, 635-641.

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14. M.Vendelin, O.Kongas, V.Saks. Regulation of mitochondrial respiration in heart cells analyzed by reaction - diffusion model of energy transfer. Amer. J. Phys. Cell. Physiol., 278(4), April 2000, 747-764.

15. V.Saks, M.Vendelin, O.Kongas, L.Kay. Creatine-phosphocreatine pathway in the intracellular networks of energy transfer and signal transduction in muscle cells. In: R.Paoletti et al. (eds.). Creatine. From Basic Science to Clinical Application. Kluwer, Dordrecht, 2000, 1-9.

16. A.Szekeres, J.Engelbrecht. Coupling of generalized heat and moisture transfer. Periodica Polytechnica, Ser. Mech. Eng., 2000, 44, N 1, 161-170.

17. M.Kutser. Mechanics at the Institute of Cybernetics. Proc. Estonian Acad. Sci. Eng., 2000, 6, 3, 230-251.

18. A.Salupere, O.Ilison. On solitonic structures in microstructured materials. In: J. Hellesland, H. Osnes and G.Skeie (eds.) Proc. 13th Nordic Seminar on Computational Mechanics (NSCM-13), Oslo, 20-21 October, 2000, 70-73.

19. A.Braunbrück, A.Ravasoo. Simulation of nonlinear wave interaction for elastic material properties evaluation. In: J. Hellesland, H. Osnes and G.Skeie (eds.) Proc. 13th Nordic Seminar on Computational Mechanics (NSCM-13), Oslo, 20-21 October, 2000, 66-69.

20. A.Berezovski, J.Engelbrecht, G.A.Maugin. Thermoelastic wave propagation in inhomogeneous media. Arch. Appl. Mech., 2000, 70, 694-706.

21. A.Luik, L.Kulmar, K.Rannat, V.Reedik. Fast Kalman filter for data processing in distributed mechatronic systems. In: The 7th Mechatronic Forum International Conference and Mechatronics Education Workshop, Atlanta, 6-8 September 2000, Elsevier, 2000, 1-6 (CD-ROM).

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23. K.Meigas, H.Hinrikus, R.Kattai, J.Lass. Blood Flow Detection with Diode Laser. Ibid, CD-ROM: MO-CXH-8.

24. K.Meigas, H.Hinrikus, J.Lass. Simple Coherence Method for Blood Flow Detection. Coherence Domaine Optical Methods in Biomedical Science and Clinical Applications IV, SPIE, 24-26 January, San Jose, California, Vol.1, N9, 2000, 112-120.

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26. H.Aben, L.Ainola, J.Anton. Integrated photoelasticity for nondestructive residual stress measurement in glass. Opt. Lasers Eng., 33, 2000, 49-64.

27. H.Aben, L.Ainola. Isochromatic fringes in photoelasticity. J. Opt. Soc. Am. A, 17, 4, 2000, 750-755.

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29. H.Aben, L.Ainola, J.Anton. Integrated photoelasticity for nondestructive residual stress measurement in glass. Proc. International Conference on Trends in Optical Nondestructive Testing (Rastogi,P., Inaudi, D., eds.). Lugano, 2000, 273-284.

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31. H.Aben, L.Ainola. Optical tomography of the laser's Gaussian electric field. Optics and Laser Technology, 2000.

32. V.Abramov, R.Kerner. Exterior differentials of higher order and their covariant generalization. J. Math. Phys., 2000, 41, 5598-5614.

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Abstracts

1. J.Engelbrecht, A.Salupere, T.Sillat. Nonlinear waves in microstructured materials. In: Int. Workshop on Nonlinear Waves in Solids. June 8-11, 2000, City University of Hong Kong, p.6.

2. A.Ravasoo. Nonlinear wave interaction for material characterization. In: 4th Euromech Solid Mechanics Conference, June 26-30, 2000, Metz. Book of Abstracts II, University of Metz, p.706.

3. A.Berezovski, G.A.Maugin. Simulation of two-dimensional thermoelastic wave propagation in inhomogeneous media. Ibid. p.715..

4. P.Peterson, E. van Groesen. The direct and inverse problems of wave crests. In: Abstract Book, ICTAM 2000, Aug. 27 - Sept. 2, 2000, Chicago, IUTAM. p.44.

5. J.Engelbrecht, M.Vendelin, P.H.M.Bovendeerd, D.H. van Campen, T.Arts. Contraction of cardiac muscles and ATP consumption. Ibid. p.143.

6. O.Kongas, M.Vendelin, V.A.Saks. *In silico* regulation of oxidative phosphorylation in muscle cells in health and disease. Biophys. J., 2000, 197A, p.78.

7. O.Kongas, M.Vendelin, V.A.Saks. Regulation of mitochondrial respiration in cardiac cells in health and disease. Eur. J. Med. Res., 2000, 5, p.8.

8. A.Salupere. Technique for detection of solitons in numerical experiments and virtual soliton. In: E.Oñate, G.Bugeda, G.Suárez (eds.) Book of Abstracts of the European Cong. on Computational Methods in Applied Sci. and Eng. - ECCOMAS 2000, 11-14 Sept., Barcelona, Spain, p.774.

9. M.Lemba, M.Vendelin. Effects of nonlinearities on active stress formation in cardiac muscle in silico. In: 7th Int. Summer School on Biophysics "Supramolecular Structure and Function". Croatian Biophys. Soc., 14-25 Sept., 2000, Rovinj, Croatia, p. 102.

10. A.Stulov. Characteristics of piano hammers: theory and experiment. In: The Physics Congress 2000. The Physics of Musical Instruments 2 Conf., March 27-30, 2000, Brighton. Abstract Book, 53-54.

11. A.Ravasoo. Wave profile distortion and NDT of inhomogeneously predeformed material. In: Book of Abstracts: Elastic Waves in Nondestructive Testing. Euromech 419 Colloquium, October 3-5, 2000, Prague, Czech Republic, p. 15.

12. T.Soomere, K.Kasemets. Cyclones with anticyclonic kernel on a beta-plane. Geophys. Res. Abstr., 2, 2000 (CD-ROM).

13. T.Soomere, K.Rannat. Double monopoles in a laboratory experiment. Geophys. Res. Abstr., 2, 2000 (CD-ROM).

Essays

1. J.Engelbrecht, "Interaction of "Solitons" in a Collisionless Plasma and the Recurrence of Initial States" by N.J.Zabusky and M.D.Kruskal. In: W.Schiehlen and L. van Wijngaarden (eds.), Mechanics at the Turn of the Century, IUTAM, Shaker Verlag, Aachen, 2000, 13-14.

2. J.Engelbrecht, On tracks of Nikolai Alumäe. In: M.Kutser (ed), Institute of Cybernetics over changing times, Tallinn, IoC at TTU, 2000, 36-37 (in Estonian).

3. J.Engelbrecht, Science at the threshold of the New Century. Akadeemia, 2000, N 6, 1204-1222 (in Estonian).

4. M.Lemba, O.Kongas, M.Vendelin. Heart as it is. In: J.Engelbrecht, E.Ergma (eds.), Young Researchers, Estonian Acad. Sci., Tallinn, 2000, 62-66.

Submitted papers

1. P.Peterson, E. van Groesen. Sensitivity of the inverse wave crest problem. Wave Motion (accepted).

2. A.Ravasoo, J.Janno. Nondestructive characterization of materials with variable properties. Acta Mechanica, (accepted).

3. A.Stulov, A.Mägi. Piano hammer parameters measuring device. Proc. Estonian Acad. Sci. Engin. (accepted).

4. J.Kalda. Super-correlated percolation and gradient-limited random surfaces. Phys. Rev. Lett. (under revision).

5. A.Berezovski, G.A.Maugin. Simulation of thermoelastic wave propagation by means of composite wave-propagation algorithm. J. Comp. Physics (accepted).

6. A.Ravasoo, B.Lundberg. Nonlinear interaction of longitudinal waves in an inhomogeneously predeformed elastic medium. Wave Motion (accepted).

7. A.Salupere, J.Engelbrecht, G.A.Maugin. Solitonic structures in KdV-based higher-order systems. Wave Motion (accepted).

8. A.Berezovski, G.A.Maugin. Application of wave-propagation algorithm to 2D thermoelastic wave propagation in inhomogeneous media. In: E.F.Toro (Ed.) Godunov Methods: Theory and Applications, Kluwer, Dordrecht, 2000 (accepted).

9. J.Engelbrecht, M.Vendelin. Microstructure described by hierarchical internal variables. Rendicorti Matem. Univ. Torino (submitted).

10. T.Soomere. New insight to classical equilibrium solutions of kinetic equations. J.Nonlin. Sci. (submitted).

11. T.Soomere, K.Rannat. Cyclones with anticyclonic kernel in laboratory experiments with a cluster of vortices on a beta-plane. Environmental Fluid Dynamics (submitted).

12. T.Soomere, S.S.Zilitinkevich. Wave-induced vertical fluxes from turbulent boundary layer to stably stratified free flow. Quart. J. Roy. Met. Soc. (submitted).

13. P.Miidla, K.Rannat, J.Heinloo. Numerical stability in a model of layered structure of thermohaline fields. Proc. Estonian Acad. Sci. Phys. Math. (submitted).

5.3 Conferences

1. 20th International Congress of Theoretical and Applied Mechanics - ICTAM 2000, Chicago, Aug 27-Sept 2, 2000.
   J.Engelbrecht, M.Vendelin, P.H.M.Bovendeerd, T.Arts, D.H. van Campen, Contraction of cardiac muscles and ATP consumption;
   P.Peterson, E. Van Groesen, The direct and inverse problem of wave orests.

2. International Workshop on Nonlinear Waves in Solids, Hong Kong, June 8-11, 2000.
   J.Engelbrecht, A.Salupere, T.Sillat, Nonlinear waves in microstructured materials (invited lecture).

3. 44th Annual Meeting of Biophysical Society, New Orleans, Febr 12-16, 2000.
   M.Vendelin, Cardiac mechanoenergetics replicated by cross-bridge model.
   O.Kongas, In silico regulation of oxidative phosphorylation in muscle cells in health and disease.

4. Fractals 2000, Singapore, April 14-19, 2000.
   J.Kalda, On the multifractal properties of passively convected scalar fields.

5. 22nd International Conference on the Unity of Sciences, Seoul, Febr 9-13, 2000.
   J.Kalda, The methods of nonlinear dynamics in the analysis of heart rate variability.

6. ECCOMAS 2000, Barcelona, Sept 11-14, 2000.
   A.Salupere, Technics for detection of solitons in numerical experiments and virtual soliton concept.

7. EUROATTRACTOR 2000, Warsaw, June 6-15, 2000.
   M.Säkki, On the nonlinear measures of the heart rate variability of children.

8. 4th International Seminar on Geometry, Continua and Microstructures, Torino, Oct 26-28, 2000.
   J.Engelbrecht, M.Vendelin, Microstructure described by hierarchical internal variables.

9. Seminar on waves (Vlny), Prague, April 4, 2000.
   J.Engelbrecht, A.Salupere, O.Ilison, Solitary waves in microstructured media.
   J.Engelbrecht, M.Vendelin, O.Kongas, Mathematical modelling of cardiac dynamics.

10. 5th International Conference on Mathematical and Numerical Aspects of Wave Propagation - WAVES 2000, Santiago de Compostela, July 10-14, 2000.
    A.Berezovski, J.Engelbrecht, G.A.Maugin, Two-dimensional thermoelastic wave propagation in inhomogeneous media.

11. 4th European Solid Mechanics Conference (ESMC4), Metz, June 26-30, 2000.
    A.Berezovski, G.A.Maugin, Simulation of two-dimensional thermoelastic wave propagation in inhomogeneous media.
    A.Ravasoo. Nonlinear wave interaction for material characterization.

12. Gordon Research Conference. "Macromolecular organization and cell function". Oxford.
    M.Vendelin, O.Kongas, J.Engelbrecht, V.Saks, In silico regulation of cardiac energetics.
    O.Kongas, High apparent Km of oxidative phosphorylation for ADP in skinned fibers: where does it stem from?

13. 13th Nordic Seminar on Computational Mechanics, Oslo, Norway, Oct 20-21, 2000.
    A.Salupere, O.Ilison, On Solitonic structures in microstructured materials.
    A.Braunbrück, A.Ravasoo, Simulation of nonlinear wave interaction for elastic material properties evaluation.

14. Euromech 419 - Colloquium on Elastic Waves in Nondestructive Testing. Prague, Czech Republic, Oct 3-6, 2000.
    A.Ravasoo, Wave profile distortion and NDT of inhomogeneously predeformed media.

15. The Physics Congress 2000. The Physics of Musical Instruments 2 Conference, Brighton, March 27-30, 2000.
    A.Stulov, Characteristics of piano hammers: theory and experiment.

16. Symposium on thermodynamics and the structure of biological macromolecules, New Orleans, Febr 11, 2000
    O.Kongas.

17. 2nd Colloquium on mitochondria and myopathies, Halle/Saale, Germany, March 31 - April 2, 2000.
    O.Kongas, M.Vendelin, V.Saks, Regulation of mitochondrial respiration in cardiac cells in health and disease.

18. The 7th International Summer School on Biophysics, Rovinj, Croatia, September 14-25, 2000.
    M.Lemba, M.Vendelin, Effects of nonlinearities on active stress formation in cardiac muscle *in silico.*

19. 25th General Assembly of the European Geophysical Society, Nice, April 2000.
    T.Soomere, Wave-induced fluxes from turbulent boundary layers, (invited lecture);
    T.Soomere, K.Kasemets, Cyclones with anticyclonic kernel on a beta-plane;
    T.Soomere, K.Rannat, Double monopoles in a laboratory experiment.

20. BOOS meeting, Copenhagen, October 2000.
T.Soomere, Wave and wind anomalies in the coastal zone of Saarema (Ösel) and Hiiumaa (Dagö).

21. The 7th Mechantronics Forum: Int. Conf. and Mechatronics Education Workshop, Atlanta, September, 2000.
A.Luik, L.Kulmar, K.Rannat, V.Reedik, Fast Kalman filter for data processing in distributed mechatronic systems.

22. Specific programme "Virtual Laboratories" (SP-III) of EC 5. FP Programme "ETNET 21 Environment-Water", Regional meeting "Baltic virtual laboratory: education and research in water related sciences", Riga, December 2000.
T.Soomere, High-resolution wave modelling in Gulf of Riga.

23. Int. Conf. on Clifford Analysis its Applications and Related Topics, Bejing, Aug. 1-6, 2000.
V.Abramov, Higher order exterior calculus, generalized Clifford algebras and gauge theories.
M.Rahula, Lie calculus in dynamical systems.

24. 3rd Int. Conf. Differential Equations and Applications, Sankt-Petersburg, June 12-17, 2000.
M.Rahula, Lie calculus in dynamical systems.

5.4 Seminars outside the home Institute

1. J.Engelbrecht, Nonlinear waves in dispersive media. Institute of Mechanics, Chinese Academy of Sciences, Bejing, June 2000.

2. J.Kalda, On the scaling properties of random self-affined surfaces, University of Oslo, Sept. 2000.

3. P.Peterson, Conserving nonlinearity. Dept. of Applied Mathematics, University of Twente, Nov., 2000.

4. O.Kongas, Possible origins of high K_m in skinned fibres. Dept. of Biology, Free University Amsterdam, Oct., 2000.

5. O.Kongas, High apparent K_m of oxidative phosphorylation for ADP in skinned fibres: where does it stem from? Institute of Cardiovascular Research, Free University of Amsterdam, Dec., 2000.

6. M.Vendelin, Heart respiration *in silico*. Laboratory of Bioenergetics, University of Grenoble, Nov., 2000.

7. M.Vendelin, Functional coupling between ANT and CK in *in vivo* and *in silico*. INSERM unit 441, University of Bordeaux, Dec., 2000.

8. T.Soomere, Unusual behaviour of vortices on a beta-plane, Uppsala University, October 2000.

5.5 Supportive grants (travel, etc.)

1. ETF travel grants for young researchers - O.Ilison, A.Braunbrück.
2. ETF young scientists award grants - M.Vendelin, P.Peterson.
3. IUTAM grant for participation in ICTAM 2000 - P.Peterson.
4. PhD students support: M.Vendelin, P.Peterson.
5. City University of Hongkong – travel grant to J.Engelbrecht to participate in the Workshop Nonlinear Waves in Solids, Hongkong.
6. Messina University grant to J.Engelbrecht for lecture course in Messina.
7. University of Turin grant to J.Engelbrecht for lecture course in Turin.
8. Czech Academy of Sciences grant to A.Ravasoo for attending the Euromech colloquium in Prague.
9. University Paris 6, grant to A.Berezovski for attending the conference in Santiago di Compostela.
10. NDS-N grants to O.Ilison, A.Braunbrück to attending the seminar in Oslo.
11. Estonian Academy of Sciences and Royal Norvegian Academy of Sciences grant to J.Kalda for studies in Oslo (two weeks).
12. Conference "Unity of the Sciences", PC grant to J.Kalda for attending the conference in Scoul.
13. Tallinn Piano Factory support to A.Stulov for attending the conference in Brighton.
14. TTU Development Fund, scholarship to M.Lemba.
15. EC grant to M.Säkki to participate in the Summer School EUROATTRACTOR 2000 in Warsaw.
16. Visby fellowship to K.Kasemets for covering living expenses in Uppsala (9 months, 2000-2001).
17. Chinese Academy of Sciences - grant to M.Rahula and V.Abramov for attending the conference in Bejing.
18. University of Paris 6 - grant to V.Abramov for a stay in the Dept. of Physics.

5.6 International cooperation

1. Within grant projects:
   - NATO Collaborative Linkage Grant "Thermomechanics of progress and stability of phase interfaces (crystals, alloys)", partners University of Paris 6, Technical University Berlin, Institute of Cybernetics;
   - INSERM (France) grant "Modélisation biomathématique pour l'étude du métabolisme énergetique", partners University of Grenoble, University of Bordeaux, Institute of Cybernetics;
   - ESF Programme NATEMIS. Nonlinear Acoustic Technique for Micro-Scale Damage Diagnostics", partners from many European centres in Italy, The Netherlands, Czech Republic, etc.

2. Within collaborative agreements:
Institute of Cybernetics:
- Eindhoven University of Technology;
- University of Paris 6;
- Budapest Technical University;
- Helsinki University of Technology;
- Technical University of Denmark.

Dept. of Geometry, Tartu University:
- University of Paris 6 and Wroclav University.

3. Within informal contacts: University of Turin, University of Uppsala.

5.7 Research programmes (national)

1. Nonlinear Dynamics (part of the Estonian Programme on Mechanics).
2. Mathematical Modelling of Physiological Processes (Part of the Estonian Programme on Biomedical Engineering).
3. Research programme of Tallinn Piano Factory and Institute of Cybernetics.
4. Physiological signal processing (part of the Estonian Programme on Biomedical Engineering).
5. Electromagnetic radiation interaction with human being (part of the Estonian Programme on Biomedical Engineering).

5.8 Teaching activities

1. A.Salupere: courses in TTU on
   - Statics
   - Dynamics
   - Continuum mechanics
2. J.Engelbrecht: course in TTU on
   - Mathematical modelling
3. J.Engelbrecht, J.Kalda, M.Vendelin: Estonian Society of Physics, Summer School for MSc and PhD students - one day course (8h) on biophysics, Kääriku, Estonia.
4. J.Engelbrecht: University of Turin, Department of Mathematics, PhD course "Nonlinear evolution equations" (6h).
5. J.Engelbrecht: University of Messina, Department of Mathematics, PhD course on Nonlinear Dynamics (4 lectures).
6. J.Kalda: Preparation of the Estonian and Finnish team of five students to the XXXI International Physics Olympiad in Leicester (U.K.).
7. J.Engelbrecht: supervising PhD students;
   J.Kalda, A.Ravasoo, A.Salupere, A.Berezovski: supervising MSc students;
   M.Vendelin: supervising BSc students.

8. T.Lipping: Signal Processing, TTU, Spring 2000.
9. T.Lipping: Physiological Signal Processing, TTU, Autumn 2000.
10. H.Hinrikus: Electromagnetic Fields and Waves, TTU, Spring 2000.
11. H.Hinrikus: Biological Effects of Electromagnetic Radiation, TTU, Autumn 2000.
12. K.Meigas: Microwave and Optical Engineering, TTU, Autumn 2000.
13. K.Meigas: Biomedical Instrumentation, TTU, Autumn 2000.
14. J.Heinloo: Course on Contemporary Hydromechanics, TTU.

5.9 Longer visits of fellows

1. J.Kalda: Department of Physics, University of Oslo, Oct., 2000 (two weeks).
2. P.Peterson: Department of Applied Mathematics and Mathematical Physics, University of Twente, Oct., 2000 (one month).
3. M.Vendelin: Laboratory of Bioenergetics, University of Grenoble and INSERM unit 441, Bordeaux, Nov.–Dec., 2000 (two months).
4. J.Engelbrecht: Department of Mathematics, University of Messina and Department of Mathematics, University of Turin (three weeks).
5. O.Kongas: Department of Biology, Free University Amsterdam (nine months).
6. K.Kasemets, Uppsala University (nine months).
7. T.Soomere, Uppsala University (ten months).
8. V.Abramov, University of Paris 6 (one month).

5.10 Visiting scholars

1. Prof. Åke Öberg, Linköping University. Seminar on "New trends in biooptics".
2. Dr. K.Kahma, (Finnish Marine Research Institute). Seminar on wind waves and their operational forecast.
3. Dr. A.Szekeres, Budapest Technical University.
4. Mr. J.Novak, Institute of Thermomechanics, Czech Academy of Sciences.
5. Mr. L.Kollar, Budapest Technical University.

5.11 Theses

Institute of Cybernetics:

Promoted:
T.Ugam "Properties of shape-memory alloys" - Dipl. Eng.
M.Kukk "Solitary waves in dispersive media with periodical forcing" - BSc. In progress:
M.Vendelin, O.Kongas, J.Anton - PhD;
O.Ilison, A.Braunbrück, M.Säkki, T.Ugam, N.Ilves - MSc;
M.Lemba, K.Enno, P.Rask, A.Koitmäe, A.Errapart - BSc.

Tartu University:

Promoted:
K.Kuusmets "Cospoidal Singularities" - BSc;
E.-K-Niilo "Higher-order contacts of lines and surfaces" - BSc;
R.Tenson "Cardano mappings" - BSc;
A.Filonov "Geometrical meaning of symmetries of differential equations - MSc;
N.Zaitseva "Cartan distribution and geometry" - MSc.

In progress:
O.Bogdanova, D.Tselniko - MSc;
A.Filonov, N.Zaitseva, N.Bazunova - PhD.

Estonian Marine Institute:

In progress:
K.Kasemets - PhD.

Centre of Biomedical Engineering:

In progress:
T.Lipping - PhD.

5.12 Distinctions

T.Soomere - Nikolai Alumäe Academic Lecture 2000.

5.13 Exhibitions, fairs

1. Technology fair 2000, Tallinn, May 18-20, 2000: A.Berezovski. Application of wave-propagation algorithm to 2D thermoelastic wave propagation in inhomogeneous media.
2. Hanover Mess, March 2000: K.Meigas, H.Hinrikus, J.Lass, R.Kattai. Laser Device for Cardiovascular Diagnostics.

5.14 Conferences and seminars

Seminars (over academic terms):
- cell energetics;
- thermodynamics;
- solitons;
- thermomechanics of moving phase boundaries.

International Glass Stress Summer School, supervisor H.Aben, 11.10 - 15.10.2000, Tallinn, Estonia.

6. Summary

6.1 Conclusions and Prospects

To sum up, several projects are now developing in a good pace. The prospects can be derived into two groups: activities in the short time period (next year) and activities with longtime prospect. **For the year 2001**, the hot problems are the following:

- *in silico* modelling of cell energetics;
- acoustodiagnostics for dispersive materials;
- soliton patterns in the long run (energy distribution in a conservative system);
- dynamics of stress-induced phase fronts;
- calibration of piano hammers;
- fractality of self-affine surfaces:
- calculation of the correlation dimension of heart beats;
- high-resolution wind wave modelling in Estonian coastal area;
- anomalous behaviour of vortices in the beta plane.

¿From the organizational side, we plan applying to be included into the national list of centres of excellence in research, widening our collaborative network and applying for new grants. We start preparing a Euromech Colloquium in 2002 (application needed in April 2001) on Nonlinear Dynamics of Microstructured Materials (together with the University of Paris 6). Another meeting on Cell Energetics (together with Tartu University and University of Grenoble) is planned later.

The heart of the Computing Centre now is a cluster of 18 Athlons and Alphas, which has been modelled after Los Alamos National Laboratory. Linux is mostly used.

We estimate in 2001 the promotion of 2 PhDs, 3 MScs, and 4 BScs.

In a long run, the aims involve the following:

- more defined *Physiome* project (or a programme) together with the Laboratory of Bioenergetics of the National Institute of Chemical Physics and Biophysics and Tartu University as a part of an international network;
- more attention to meso- and nanomechanics with dispersive effects;
- studies of surface waves in strongly stratified sea combining the efforts of the teams in the Institute of Cybernetics at TTU and the Estonian Institute;
- studies of surface waves induced by high-speed craft traffic;
- application of fractal theory and lattice modelling in interdisciplinary areas including social systems.

6.2 A view ahead: invited and/or accepted presentations for conferences in 2001

The presentations include the following: IUTAM Symposium on Computational Mechanics of Solid Materials at Large Strains (Stuttgart), IUTAM Symposium on Micromechanics of Martensitic Phase Transformation in Solids (Hong Kong), XXXIVth International Congress of Physiological Sciences (Christchurch, New Zealand), Fenno-Ugric Days of Mechanics (Budapest), 26th General Assembly of the European Geophysical Society (Nice), Ultrasonics International 2001 (Delft), International Workshop Advances in Signal Processing for NDE of Materials (Quebec), the 9th International Python Conference (Long Beach, California), etc.