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Spis prelegentów

KAPITAŁ LUDZKI
CZŁOWIEK – NAJLEPSZA INWESTYCJA!

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1 Prelegenci

1.1 Fractal scaling of the vascular tree: can it promote hypertension?

Teodor Buchner, Warsaw University of Technology, Faculty of Physics, Working Group for Cardiovascular Physics.

We analyse the possible role of fractal scaling in propagation of pulse wave. We consider a simplified numerical model of wave propagation in the vascular tree, which exhibits fractal scaling - a Duan–Zamir model. We consider separate scaling for the diameter and the length of each vessel segment. We show, that fractal scaling may reduce or enhance the phenomenon of pressure peaking and the peak pressure does not necessarily appear in the terminal segments of the tree. We also study the transmittance of the tree in a low frequency range i.e. below the heart frequency. We show that in this frequency range there appears a prominent maximum of transmittance. Its position depends rather on fractal scaling than on the total length of the tree. Hence it is rather a scale-invariant property than a typical resonance. The presence of this maximum may serve as an explication of the so-called Mayer waves. The role of this low frequency pressure waves, which appear during hypovolemic state, e.g. after acute haemorrhage, could be supplementation of a blood flow. Regardless of the exact mechanism in which the Mayer waves were initiated, their propagation at low frequencies should be much easier than for any higher frequencies. Finally, the total peripheral resistance is shown to depend on fractal scaling parameters. This fact suggests, that in search of possible risk factors of primary hypertension we should take a closer look into the angiogenesis process, as any abnormalities of the structure of the vascular tree may result in a systematically higher value of peripheral resistance with no apparent cause. Another medical condition in which the fractal scaling may be important is the pre-eclampsia: medical condition related with an abnormal structure of placenta.
Współautor: Tomasz Sobiech

1.2 Measuring Information Dynamics in Complex Physiological Networks

Luca Faes, University of Trento

In the emerging field of network physiology [1], the human organism is viewed as an integrated network where the cardiac, circulatory, respiratory, and cerebral systems, each with its own internal dynamics, continuously interact with each other to preserve the overall physiological function. Being able to describe the joint system behavior and the contribution of the different observed parts to it may yield fundamental insight on the functioning of the networks underlying the regulation of physiological rhythms.

The proposed lecture will introduce an unifying approach for the quantitative description of physiological networks framed in the novel research field of information dynamics [2]. The approach is based on interpreting the physiological systems under analysis as dynamical systems, mapping the system behavior into a set of variables, and describing the time evolution of these variables –collected in the form of time series data– using information-theoretic analysis tools. These tools are developed essentially by incorporating dynamical and directional information into classic information theoretic measures like (conditional) entropy and mutual information. For instance, in a network of dynamical systems formed by a target system Z and two (possibly multivariate) source systems X and Y, the predictive entropy (PE) about Z is measured as the amount of information carried by the present state of Z which can be predicted from the past states of X, Y and Z; the PE can be decomposed as the sum of the self entropy (SE) of Z and the transfer entropy (TE) from X,Y to Z, reflecting respectively information storage and transfer in the network; the TE can be further expanded as the sum of the TE from X to Z conditioned to Y, the TE from Y to Z conditioned to X, plus the redundant entropy (RE) relevant to the interaction between X and Y while transferring information to Z. The main appeal of these measures is in the fact that, taken together, they allow to dissect the general concept of 'information processing' into essential sub-components of meaningful interpretation: the information produced by a dynamical system, the information stored in the system, the information transferred to it from the other connected systems, and the informational character (synergistic or redundant) of the information transferred from multiple source systems to a destination system.

In the lecture, I will first provide theoretical definitions of information dynamical measures for the study of networks of interacting dynamical systems, drawing a connection between dynamical system theory and information theory via the time delay embedding procedure, and showing how the system states can be described in terms of random process and then characterized by entropy-based functionals. Then, I will present two main approaches for the practical computation of these measures, dealing with theoretical and practical issues that hamper their estimation from real-world time series: the linear model based approach provides an efficient and compact representation of the system interactions and is closely related to the frequency domain representation of such interactions; the model-free approach, implemented using different entropy estimators, allows the de-

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tection of any type of linear or nonlinear dynamical interaction. The advantages and limitations of the two approaches will be pinpointed showing their application in simulations of networks of stochastic and deterministic coupled systems. Finally, practical applications of the framework for the analysis of physiological networks will be discussed, including the study of the mechanisms underlying physiologic cardiovascular and cardiorespiratory interactions, of cerebrovascular regulation in neurally-mediated syncope, and of brain-brain and brain-heart interactions during sleep.

Literatura

[1] Bashan A, Bartsch RP, Kantelhardt JW, Havlin S and Ivanov PC, Network physiology reveals relations between network topology and physiological function. Nature Communications 3, 2012.

[2] Faes L and Porta A. Conditional entropy-based evaluation of information dynamics in physiological systems. In: Vicente R, Wibral M, Lizier JT, editors. Directed Information Measures in Neuroscience. Berlin: Springer-Verlag, 2014: 61-86.

1.3 A model of immune response with delays

Urszula Foryś, Uniwersytet Warszawski

Recently, Feyissa and Banerjee [1] proposed a model of interactions between immune system and cancerous cells with two delays included. Analysis presented in [1] is made under the assumption that solutions are positive. However, this statement is not true. We propose a wide class of initial functions for which the solutions are negative. Moreover, the model is incorrectly constructed in our opinion, and therefore we propose corrected version, where typically delays do not lead to destabilisation, while the main result for [1] is appearance of delayed-induced oscillations. This is not the first time (cf.[2]) when oscillations due to delays are not the main feature of the corrected model, and also not the first model proposed in the literature for which solutions are negative, while the authors of the model do not pay attention to that problem (cf.[3]).

Literatura

[1] S. Feyissa, S. Banerjee, *Delay-induced oscillatory dynamics in humoral mediated immune response with two time delays*, Nonlinear Analysis: RWA 14(1) (2013) 35–52.

[2] J. Miękisz, J. Poleszczuk, M. Bodnar, U. Foryś, *Stochastic models of gene expression with delayed degradation*, Bull. Math. Biol. 73(9) (2011) 2231–2247.

[3] U. Foryś, M. Bodnar, J. Poleszczuk, *Negativity of delayed induced oscillations in a simple linear DDE*, Appl. Math. Lett. 24(6) (2011) 982–986.

1.4 The assessment of cardiovascular regulation with implementation of novel mathematical tools

Beata Graff, Medical University of Gdansk

The variability of cardiovascular parameters is usually not easy to analyse. Collected recordings are often short with artifacts, missing points or nonstationarities. The assessment of the interaction between various systems is even more difficult. Novel mathematical tools which allow to better understand complex mechanisms of cardiovascular regulation are discussed in the presentation. The examples of clinical questions from own studies and methods used to answer them are given.

1.5 Mathematical and numerical predictions of the hematopoietic stem cell based therapy of immunosuppressive viral infections

Adam Korpusik, Faculty of Technical Sciences, University of Warmia and Mazury, Olsztyn, Poland

Gene therapies present a great potential for treating a vast repertoire of diseases (*e.g.* cancer, viral and bacterial infections). One of such therapies utilizes hematopoietic stem cells (HSCs) of the patient to engineer virus-specific cytotoxic T lymphocytes (CTLs) that kill the infected cells. This approach is currently being discussed as a possible treatment for HIV infection. We have decided to take a look at the possible dynamics of such therapy from a mathematical perspective, using a variation of the basic mathematical model for virus-induced impairment of help (originally proposed by D. Wodarz, P. Klenerman and M. Nowak).

We have examined how the additional influx of engineered virus-specific CTLs influences the immune response in different stages of infection. Next, the model was expanded to describe the dynamics of a single injection of CD8+ T lymphocytes derived from hematopoietic stem cells. Our results indicate that therapy should limit the immune impairing effect of the infection, resulting in restoration of the immune response, reduced

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T helper cell depletion and suppression of plasma viremia. Moreover, in some patients, a single, large enough dose of genetically derived CTLs may lead to long-term immune control of the infection.

1.6 Subdiffusion-reaction process in a membrane system

Tadeusz Kosztołowicz, Institute of Physics, Jak Kochanowski University, Kielce

We consider the subdiffusion process with reactions of a type $A + B \rightarrow B$ in a membrane system in which particles A are assumed to be mobile whereas B are assumed to be static. This process is considered within a persistent random walk model in a system with both discrete time and discrete space variable. Then the obtained results will be transformed to both continuous time and continuous space variable. The potential applications of the obtained results in biology will be shown.

1.7 Simple applied mathematics in programming decompression systems after long saturation dives

Jacek Kot, National Center for Hyperbaric Medicine, Institute of Maritime and Tropical Medicine in Gdynia, Medical University of Gdańsk

During diving, as ambient pressure increases, inert gas from breathing mixture (usually nitrogen or helium) is dissolved in tissues, creating in the body a supersaturated state. After completing the bottom phase the process of decompression starts and, if ascent is too rapid, the dissolved inert gas in the blood and tissues can form bubbles that cause tissue injury and decompression sickness. When dive lasts days or weeks all body tissues are fully saturated and desaturation process is very slow and delicate. For nitrogen based gas mixtures (i.e. compressed air) decompression from saturation takes about 18 hours per every 10 meters of depth. During such decompression only 1.2 ml/min of nitrogen is eliminated while at the same time in all metabolic processes 250 ml/min oxygen are consumed to generate energy with side production of 200 ml/min of carbon dioxide. Interestingly, elimination of inert gas during saturation process is driven by oxygen.

In Poland there is a system for decompressions after saturation expositions in middle range of pressures (up to 11 ATA, equal to depth of 100 meters) using air, nitrox (mixture of nitrogen and oxygen) and trimix (mixture of helium, nitrogen and oxygen).

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This system uses a computerized model of desaturation of nitrogen and helium from human body as depending of driving force (?P) – pressure gradient mathematically equal to partial pressure of oxygen in breathing mixture – and the longest tissue half-time of the slowest limiting compartment (maxT1/2) of the human body. The system calculates the rate of decompression as based on composition of breathing gases (partial pressure of oxygen and fraction of nitrogen and helium). Decompressions are conducted using continuous method of decreasing of ambient pressure. In total we have conducted 118 man-expositions lasting approx. 1 week each and there was no single case of decompression sickness in all expositions conducted for research purposes proving the correctness of the model, its parameters and calculations.
Współautor: Zdzislaw Sicko

1.8 Macroscopic limits and self–organization

Mirosław Lachowicz, University of Warsaw, Faculty of Mathematics, Informatics and Mechanics, Institute of Applied Mathematics and Mechanics

The macroscopic limits of the kinetic models for interacting entities are studied. The kinetic model is one–dimensional and entities are characterized by their position and orientation (+/-) with swarming interaction controlled by the sensitivity parameter. The macroscopic limits of the model are considered for solutions close either to the diffusive (isotropic) or to the aligned (swarming) equilibrium states for various sensitivity parameters. In the former case the classical linear diffusion equation results whereas in the latter a traveling wave solution does both in the zeroth ("Euler") and first ("Navier–Stokes") order of approximation. Some generalizations and the solitarious as well as swarm behaviors are discussed.

Literatura

[1] J. Banasiak, M. Lachowicz, *On a macroscopic limit of a kinetic model of alignment*, Math. Models Methods Appl. Sci., **23** (14), 2013, 2647-2670.

[2] J. Banasiak, M. Lachowicz, *Methods of Small Parameter in Mathematical Biology*, Birkhäuser 2014.

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1.9 The modelling of carious lesion progress

Katarzyna D. Lewandowska, Department of Radiological Informatics and Statistics, Medical University of Gdańsk

A carious lesion in the tooth enamel is a result of a chemical reaction between mobile organic acids and static hydroxyapatite. Hydroxyapatite is the main component of human tooth enamel, whereas, organic acids are produced in dental plaque by oral microorganisms which metabolize simple sugars from the diet. The organic acids can be transported into the enamel in a dissociated or undissociated form, which depends on the pH of the dental plaque. The transport of ions is diffusive and is motivated by the small diameter of the hydrogen ions compared to the size of the enamel tubules, whereas, when large acid molecules move into the enamel, subdiffusion occurs. We propose a theoretical model of carious lesion progress utilizing the (sub)diffusion–reaction equations. We will also find that the time evolution of the lesion depth in the cases of acid transport, normal diffusion and subdiffusion, is a power function of time $x_f \sim t^{\alpha/2}$. This result is also in accordance with the experimental data.
Współautor: Tadeusz Kosztołowicz

1.10 Visualization of heart rate dynamics by networks tools

Danuta Makowiec, University of Gdańsk

The transition network for RR-increments is used to characterize dynamics of RRintervals for healthy humans. The network vertices represent different changes in lengths of RR-intervals, the directed and weighted edges correspond to consecutive in time RR increments. The adjacency matrix of this transition network provides a graphical tool which is useful in the assessment of short-term cardiac regulation. As an example (which contour plot is shown in the figure above), the method is applied in detecting differences between diurnal activity and nocturnal rest for healthy and young people. The blue regions describe events more probable in nocturnal heart rhythm, the red region correspond to events more characteristic for diurnal activity. The probability labels are in percent. Together the characterization by RR interval patterns is added.

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1.11 Cerebral Autoregulation in mathematical equations

Kamila Mazur, Gdańsk University of Technology, Faculty of Ocean Engineering and Ship Technology

Cerebral Autoregulation (CA) is integral and very important process of maintaining stable cerebral perfusion and brain tissue oxygenation against changes in arterial blood pressure. A healthy human brain is perfused with blood flowing laminarly through cerebral vessels, providing brain tissue with substrates such as oxygen and glucose. It turns out that CBF is relatively stable, with typical values between 45 and 65 ml $\cdot$ 100 g tissue^{-1} min^{-1}, despite variations in systemic pressure as large as 100 Torr. This phenomenon is known as cerebral autoregulation and has been thoroughly documented not only in humans, but also in animals. In this review, I evaluate relevant studies that challenge established paradigms about how the cerebral perfusion pressure and blood flow are related. The most popular authors of this studies is M. Latka, M. Czosnyka, Yu-Chieh Tzeng and M. Ursino. M. Latka et. al studied dynamics of instantaneous phase difference $\Delta\varphi$ between the fluctuations of arterial blood pressure (ABP) and cerebral blood flow velocity (CBFV) in a middle cerebral artery. M. Czosnyka and J. D. Pickard present relationship between intracranial pressure, cerebral blood and cerebrospinal fluid. M. Ursino et al show analyze changes in cerebral hemodynamics and intracranial pressure evoked by mean systemic arterial pressure and arterial CO_2 pressure challenges in patients with acute brain damage. Yu-Chieh Tzeng and Philip N. Ainslie conclude that the physiological properties of CA remain inconclusive, many extant methods for CA characterization are based on simplistic assumptions that can give rise to misleading interpretations and robust evaluation of CA requires thorough consideration not only of active vasomotor function, but also the unique properties of the intracranial environment.

1.12 Geometry of physical space–time and regular accelerating Universe

Albert Minkevich, Department of Physics and Computer Methods, Warmia and Mazury University in Olsztyn

The modern theory of fundamental physical interactions is founded on the principle of local gauge invariance. The application of this principle for the purpose of introduction of gravitational interaction leads to generalization of metric theory of gravity, if the gauge

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group corresponding to gravitational interaction includes, besides 4-parametric translations group, also the Lorentz group. Corresponding gauge theory is gravitation theory in 4-dimensional physical space-time with the structure of Riemann-Cartan continuum named Poincaré gauge theory of gravity (PGTG). PGTG is a natural and in certain sense necessary generalization of metric theory of gravitation.

Satisfying the correspondence principle with general relativity theory (GR) in linear approximation, the PGTG leads to the change of gravitational interaction in comparison with GR and Newton's gravitation theory by certain physical conditions. In particular, PGTG leads to gravitational repulsion effect in the case of usual gravitating systems with positive values of energy density and pressure at extreme conditions (extremely high energy densities and pressures near some limiting energy density) [1] and also to the vacuum repulsion effect [1]. This allows to solve some principal problems of GR, in particular the problem of cosmological singularity and also the problem of dark energy. Isotropic cosmology built on the base of PGTG allows to build totally regular models of accelerating Universe without using the notion of dark energy [3, 4] (see lecture at Intern. School on Gravitation and Cosmology GRACOS-2014, Kazan, Russia www.rusgrav15.kpfu.ru).

Literatura

[1] Minkevich A.V., JETP Letters, 94, No 12, 831 (2011).

[2] Minkevich A.V., Mod. Phys. Lett. A, 26, No 4, 259-266 (2011) (Preprint Arxiv:1002.0538 [gr-qc]).

[3] Minkevich A.V., Garkun A.S., Kudin V.I., JCAP, 03, 40 (2013) (Preprint Arxiv: 1302.2578 [gr-qc]).

[4] Minkevich A.V., Modern Phys. Lett., A28, No 21, 1350090 (2013).

1.13 The Boltzmann equation for a stochastic particle system

Andrzej Palczewski, Faculty of Mathematics, Informatics and Mechanics, University of Warsaw

In the classical mechanics, motion of an overall many-particle system is represented by a curve in the phase space, which is also termed a phase space trajectory and determined by solutions of the Hamiltonian equations. The variety of interaction potentials between particles regulates behaviour of dynamics of systems. In a gas, for instance, close interactions between molecules (atoms) are typically characterized by some kinds of repulsive potentials, e.g. electrostatic potential of charged particles $\Phi(r) = \frac{kQ}{r}$, van der Waals potential $\Phi(r) = \frac{A}{r^{12}}$, $A > 0$, or Yukawa potential $\Phi(r) = \frac{\exp(-0.2r)}{r}$.

The integrability of such a system is in general a very complicated problem (in majority of cases the integrability is lost). What is considered instead is a large N limit, called the thermodynamic limit, in which the phase space curve is irrelevant and the system is described by its average behaviour. In the thermodynamic description we can consider a number of different scaling when passing to the limit. In this paper we consider so-called strong coupling, where the size of the particle interaction potential is of order $O(1)$ but its range is small.

The aim of this paper is the analysis of the time evolution of a system of gas particles interacting by smooth binary potentials with additional stochastic perturbations. Hamiltonian systems with a stochastic perturbation of momenta by Brownian motion were studied by several authors (cf. [1], [2], [4]). In this paper we present a generalization of this approach, including an additional (independent) stochastic perturbation of positions of particles interacting through a smooth repulsive potential. Such systems appear, for instance, in accelerator physics and describe synchrotron oscillations of particles in storage rings under the influence of external, fluctuating electromagnetic field. The first goal of this paper is to derive the Liouville equation for a stochastically perturbed N-particle distribution function.

The knowledge of the N-particle distribution function is however not of great interest when we are interested in the limit $N \to \infty$. More interesting is the restricted picture of one-particle distribution function. As we know from the classical kinetic theory this function fulfills the Boltzmann equation which, at least formally, can be derived from the Liouville equation for the N-particle distribution function. This approach will also used in the present paper. After deriving the Liouville-like equation we present a formal derivation of the equation for a one-particle distribution function. This derivation goes through a BBGKY hierarchy and follow classical approach. An important extention in comparison to old papers is the use of the results of Gallagher et al. [3] which makes the derivation rigorous.

Literatura

[1] S. Albeverio, A. Hilbert, V. Kolokoltsov, *Transience of stochastically perturbed classical Hamiltonian systems and random wave operators*, Stochast. Stochast. Rep., vol.

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60, 41–55 (1997).

[2] S. Albeverio, A. Hilbert, E. Zehnder, *Hamiltonian systems with a stochastic force: nonlinear versus linear, and a Girsanov formula*, Stochast. Stochast. Rep., vol. 39, 159–188 (1992).

[3] Gallagher, I., Saint-Raymond, L. and Texier, B. *From Newton to Boltzmann: the case of shortrange potentials*, Preprint 2012.

[4] V. N. Kolokol'tsov, R. L. Schilling, A. E. Tyukov, *Transience and non-explosion of certain stochastic Newtonian systems*, EJP, 7, 1–19 (2002).

1.14 Nonlinear Dynamics of The Heart

Ulrich Parlitz, Max Planck Institute for Dynamics and Self-Organization

In our lectures we shall present and discuss the complex spatial-temporal dynamics underlying physiological and pathological states of the heart. We shall show how nonlinear dynamics and statistical physics provide novel analytical concepts to enhance understanding of cardiac dynamics and arrhythmias, including experimental and theoretical approaches towards modeling, analysis and control of electrical forms of heart disease.

The theory of dynamical systems plays a central role in integrating biological experiments with mathematical developments. This approach will be applied to cardiac arrhythmias, a highly significant cause of mortality and morbidity worldwide. The term dynamical disease was coined for cardiac arrhythmias, suggesting that they can be best understood from the dynamical system's perspective, integrating multidisciplinary research on all relevant spatial and temporal scales.

In the lecture we shall explain how cardiac arrhythmias are a result of underlying complex spatial-temporal electrical excitation patterns following fast developing electromechanical instabilities. These dynamical states can be detected and classified using time series analysis. Furthermore, mathematical models of (collective) cell activities will be introduced and evaluated. Finally, a novel approach (LEAP) for terminating cardiac arrhythmias using low-energy pulses will presented.

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1.15 Effect of apnea on relationship between blood pressure and pial artery pulsation oscillations at human cardiac frequency

Paweł Winklewski, Institute of Human Physiology, Medical University of Gdańsk, Gdańsk, Poland

The interplay between arterial blood pressure (BP) and cerebral blood flow (CBF) fluctuations differs at higher frequencies compared to those seen in the low frequencies of the spectrum. The abrupt fall in BP-CBF synchronization at 0.07 Hz marks the transition from strong high frequency phase synchronization to low frequency phase variability. In healthy individuals, the phase difference changes slowly over time, with an almost uniform distribution at very low frequencies (0.02-0.07 Hz); this is considered an inherent property of an intact cerebral autoregulation (CA) system. For this reason, studies on CA have mostly focused on the low frequency part of the spectrum.

Nevertheless, pial artery adjustments to changes in BP may last only seconds in humans. Using a novel method called near infrared transillumination backscattering sounding (NIR-T/BSS) that allows for the non-invasive measurement of pial artery pulsation (cc-TQ) in humans, we aimed to assess the relationship between spontaneous oscillations in BP and cc-TQ at frequencies between 0.5 Hz and 5 Hz. We hypothesized that analysis of very short data segments would enable the estimation of changes in the cardiac contribution to the BP vs. cc-TQ relationship during very rapid pial artery adjustments to external stimuli.

BP and pial artery oscillations during baseline (70 s and 10 s signals) and the response to maximal breath-hold apnea were studied in nine healthy subjects. The cc-TQ was measured using NIR-T/BSS; cerebral blood flow velocity, the pulsatility index and the resistive index were measured using Doppler ultrasound of the left internal carotid artery; heart rate and beat-to-beat systolic and diastolic blood pressure were recorded using a Finometer; end-tidal CO2 was measured using a medical gas analyzer. Wavelet transform analysis was used to assess the relationship between BP and cc-TQ oscillations.

The recordings lasting 10 s and representing 10 cycles with a frequency of 1 Hz provided sufficient accuracy with respect to wavelet coherence and wavelet phase coherence values and yielded similar results to those obtained from approximately 70 cycles (70 s). A significant increase in wavelet coherence between augmented BP and cc-TQ oscillations was observed by the end of apnea.

Wavelet transform analysis can be used to assess the relationship between BP and cc-TQ oscillations at cardiac frequency using signals intervals as short as 10 s. Apnea

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increases the contribution of cardiac activity to BP and cc-TQ oscillations.

Coauthors: Gruszecki M.[2], Wolf J.[3,5], Swierblewska E.[3], Kunicka K.[3], Wszedybyl-Winklewska M.[1], Guminski W.[4], Zabulewicz J.[1], Frydrychowski A.F.[1], Bieniaszewski L.[3], Narkiewicz K.[3,5]

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4. Department of Computer Communications, Gdansk University of Technology, Gdansk, Poland;
5. Department of Cardiovascular Diseases, International Clinical Research Center, St. Anne's University Hospital in Brno (FNUSA), Brno, Czech Republic.

1.16 Time irreversibility and multifractality of heart rate variability in aortic valve stenosis – risk of valve replacement surgery

Jan J. Żebrowski, Warsaw University of Technology

Arterial valve replacement surgery is conducted when the arterial valve leading out of the heart into the main artery becomes narrowed. A number of factors may lead to this condition but in recent years the number of arterial stenosis patients is growing rapidly and the valvular disease are expected to be the next great epidemic. We studied a group of 385 arterial stenosis patients of whom 16 had died in the perioperational period (up to 30 days of the operation). Each patient had a heart rate variability recording made prior to the operation in addition to the full set of medical diagnostics including echocardiography. We formed 16 age, sex and BMI adjusted control pairs for each person who died in the postoperative period. Our aim was to find indications of the risk of arterial valve replacement surgery based on the medical data and heart rate variability properties. Besides standard, linear heart rate variability methods, we used indexes of time irreversibility introduced by Guzik (G%), Porta (P%), Ehlers (index E) and Hou (index D). In addition, we analyzed the multiscale multifractal properties of the heart rate variability using the Hurst surface. The nonlinear analysis method show clear indications of the risk of arterial valve replacement surgery in an increase of multifractaility and an increase of time irreversibility of the heart rate variability measured prior to the operation.

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2 Sesja plakatowa

2.1 Investigation of Total Peripheral Resistance with Approximate Entropy in diagnosis of vasovagal syndrome

Katarzyna Buszko, Department of Theoretical Foundation of Bio-medical Science and Medical Informatics, Bydgoszcz, Poland
1st Department of Cardiology, Medical University of Warsaw, Warsaw, Poland

The vasovagal syndrome (VVS) is commonly diagnosed type of syncope, however the genesis of VVS remains unclear. Typical diagnosis of VVS is based on an analysis of blood pressure (BP) and heart rate (HR), which are measured during the tilt test. Some data suggest that the fall in BP could be secondary to inadequate arterial vasoconstriction during orthostatic stress.

Blood pressure depends on total peripheral resistance (TPR) and cardiac output (CO), the latter depends on stroke volume (SV) and heart rate. Patients without systolic dysfunction have SV and CO determined mainly by venous return, whereas the arterial response is mainly manifested as TPR.

We propose an analysis of TPR recorded during the tilt tests conducted for 30 patients recommended to diagnosis of VVS. The tilt tests were performed with Task Force Monitor device. All examined patients fell in syncope in the supine test. For each patient the recorded values of TPR were analyzed in moving windows of width of 100 points. We determined Approximate Entropy ($ApEn$) for each window. We observed that, the values of $ApEn$ significantly decrease approximately form 0.9 to 0.4. The decrease occurs several minutes before the syncope. Such observations allow us to consider $ApEn$ of TPR as an indicator of vasovagal syndrome (VVS) prediction.
Współautorzy: Edward Koźluk, Agnieszka Piątkowska

2.2 Ordinal pattern statistics and permutation entropy for RR intervals during head-up tilt test

Agnieszka Kaczkowska, Gdańsk University of Technology, Poland

Distribution of ordinal patterns based on it permutation entropy can be interesting tool to distinguish various reactions to head up tilt test (HUTT). Methods are applied to RR-intervals of patients with history of syncope with positive and negative response

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to the test. Control group with patients with no syncope-history is built. Relations between distribution of the patterns and orthostatic and vasovagal effects during the test for groups are shown. Statistical differences in permutation entropy can be identified.
Współautorzy: Dorota Wejer, Danuta Makowiec, Beata Graff, Grzegorz Graff, Szymon Budrejko, Dariusz Kozłowski, Krzysztof Narkiewicz

2.3 Personal dead reckoning using foot-mounted inertial sensors for first responders

Michał Meina, University of Warsaw

Indoor Positioning System is expected to improve safety and decision making of the First Responders during fire and rescue operations. One of the challenge for construction of such system is a lack of the GNSS signal and assumption that no infrastructure could be used in indoor environment. Personal Dead Reckoning (PDR) using foot-mounted Inertial Measurement Units (IMUs) is expected to address those challenges. Although it is possible to develop positioning system using commercial-grade IMUs there are still problems that needs to be addressed.

IMU mounted on the foot or integrated with the shoe measures angular rates and acceleration in three axis. Basic idea is to integrate angular rates in order to get sensor (or foot) orientation and then double integrate acceleration with respect to the orientation to output travelled path. Unfortunately, direct integration outputs very unstable results after very short period. Popular solution to this problem is to utilize the fact that during gait cycle we can observe stance phase of the foot, in which velocity is close to zero. First integral of acceleration most probably will output different result and this information can be used to correct integration.

In this poster we will show the popular modelling technique (Kalman Filtering) that treats zero-velocity assumption as pseudo-observation. Especially we will focus on our model fusion approach that significantly improves performance of the system. Our prototype will be presented and on-field experiments will be discussed. We will address main challenges and means to overcome them, that arises in engineering and mathematical modelling field.

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2.4 Entropic descriptors as a tool for multiscale analysis of evolving patterns

Ryszard Piasecki, Institute of Physics, University of Opole

A lot of non-invasive optical imaging techniques are widely used in medical science. Frequently, valuable information provides the multiscale analysis of morphological features of grey-scale patterns. For these purposes, the researchers make use of the standard statistical tools as well as the others, which originate from physics. Such a quantity belonging to statistical physics is entropy that serves as a particularly useful tool in this field. Here we present a collection of various patterns, for real media and synthetic ones. The evolution of a spatial arrangement (or equivalently, an average inhomogeneity degree) can be quantitatively described by so-called entropic descriptors (EDs) at different length scales k [R. Piasecki, Microstructure reconstruction using entropic descriptors, Proc. R. Soc. A 467, 806 (2011); R. Piasecki, W. Olchawa, Speeding up of microstructure reconstruction: I. Application to labyrinth patterns, Modelling Simul. Mater. Sci. Eng. 20, 055003 (2012); D. Frączek, R. Piasecki, Decomposable multiphase entropic descriptor, Physica A 399, 75 (2014); W. Olchawa and R. Piasecki, Speeding up of microstructure reconstruction: II. Application to patterns of poly-dispersed islands, accepted to be published in Comput. Mater. Sci.].

The analysis of the spatial arrangement of i-th phase component one can perform making use of a phase descriptor, $ED_i = (S_{i,\max} - S_i)/\lambda$, where $S_i = k_B \ln \Omega_i$ denotes the Boltzmann entropy and $S_i = k_B \ln \Omega_{i,\max}$ means its maximal theoretical value. The $\Omega_i(k)$ is the number of realizations of a current macrostate (AM) defined as a set $\{m_i(\alpha, k)\}$ of the occupation numbers of sampling cells $k \times k$, $\alpha = 1, 2, \ldots, \lambda(k)$. In turn, $\Omega_{i,\max}$ describes the number of realizations of a reference macrostate (RM) that relates to theoretically maximal uniform configuration at a given length scale k. The observed first maximum of ED_i at the characteristic scale $k_{\max}$, quantifies a statistical dissimilarity between the current macrostate (AM) and reference one (RM). It points to a maximal local spatial inhomogeneity. Such a situation indicates for small cluster formation. One can also apply a measure of average overall spatial complexity for a given pattern, $C_\lambda = (S_{\max} - S)(S - S_{\min})/\lambda$, where $S_{\min}$ denotes a minimal theoretical entropy value. When applied to 1D evolving in time patterns, the above presented method can be a valuable extension of the entropy-based approaches to analysis of multi-component time-series.

Współautorzy: D. Frączek, W. Olchawa, R. Wiśniowski

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2.5 Mathematical modelling of solid tumour growth, sprouting angiogenesis and therapies

Krzysztof Psiuk-Maksymowicz, nstitute of Automatic Control, Silesian University of Technology, Poland

Growth of the solid tumour strongly relies on oxygen and nutrient support. Due to a fast metabolism of the tumour cells, those cells which are not in the close vicinity ot the blood vessels may undergo necrosis. Hypoxic cells typically initiate the process of angiogenesis. In this physiological process the new blood vessels grow from existing vasculature towards the source of angiogenic factors (e.g. vascular endothelial growth factor).

W have developed continuous and discrete model describing the dynamics of tumour growth and angiogenesis. Continuous part of the model is based on the multiphase model, and it is represented by a set of advection equations for different types of the cells. It is complemented by reaction-diffusion equations for oxygen, VEGF and (chemotherapeutic and anti-angiogenic) drugs. The discrete part of the model is used for modelling the angiogenesis. It enables modelling sprouting of the new vessel branches, and flow of the blood through it.

A number of simulations were performed with different model parameters in order to generate vascular networks with different vessel tortuosity and density of branches. Result of simulations of the tumour growing in a vascularised tissue with activated angiogenesis and action of two types of the therapies (chemotherapeutic and anti-angiogenic) gave a quantitative comparison of applied treatment protocols.

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Współautorzy: Mariusz Nieć, Jarosław Śmieja

2.6 Human Gait Estimation Using Body Sensor Network

Krzysztof Rykaczewski, University of Warsaw

There is a growing need for ubiquitous sensing systems that are capable of estimating the human activity. Many of nowadays applications concerns systems that can recognize walking state using limited information from a wearable sensor in indoor environments, e.g. for fire-fighters and miners. The conventional approaches have relied mainly on fixed installed infrastructure like, for instance, cameras. With this approach, however, it is difficult to capture motion in new surroundings, e.g. during fire action. Therefore, a system configured of wearable sensors is a highly promising approach.

In the poster we will propose hybrid approach for feature-based classification of activity recognition (mainly walking state) using limited information from wearable Inertial Measurement Units. We present comparative study which shows that hybrid approach is a promising method for activity reporting. The approach is validated with 5 subjects at six different gaits.

The proposed solution is to be a part of the decision support system in fire and rescue operations, and will be used in the ICRA project (Intelligent Commander's Remote Assistant), which aims to improve the safety for fire-fighters as well as the performance of fire and rescue actions.

2.7 Riesz basis in a problem of a nonhomogeneous string with damping at the end

Łukasz Rzepnicki, Uniwersytet Mikołaja Kopernika w Toruniu

This poster is concerned with the equation of a nonhomogeneous string of length one, which is fixed at the one end and damped into another with a parameter $h \in \mathbb{C}$. This problem can be rewritten as an abstract Cauchy problem for a densely defined, closed, operator A_h acting on an appropriate Hilbert space H. Under assumptions that the density function of the string $\rho \in W_2^1[0,1]$ is strictly positive and has $\rho(1) \neq h^2$ (if $h \in \mathbb{R}$), we prove that the set of root vectors of A_h form basis with parentheses in H. With the additional condition

$$\int_0^1 \frac{\omega_1^2(\rho', \tau)}{\tau^2}\, d\tau < \infty,$$

where ω_1 is the integral modulus of continuity, we show that the root vectors of the operator A_h form Riesz basis in H.
The poster is based on joint work with Alexander Gomilko.

2.8 Dynamic boundary conditions arising in superconductivity theory

Krzysztof A. Topolski, University of Gdańsk

Dynamic boundary conditions for first order PDEs are considered in the context of viscosity solutions. We are motivated with applications to superconductivity and surface evolution. The first model arises in the mean field theory of superconductivity (mean field vortex density model). A comparison principle is presented and uniqueness is proved. The main possible applications of the theorem are given. The equation is in a general form (including functional dependence).

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