Computational Nanoelectronics Laboratory

Ihor Lubashevsky
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Associate Professor

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Research activity

In FY 2012 the research conduced by the Modeling Complex Systems Laboratory (previously the Computational Nanoelectronics Laboratory) as a whole can be categorized as "Complex System Science," which is a novel interdisciplinary branch of science studding emergent phenomena met in a wide variety of systems different in nature, spanning from traditional objects of the inanimate world and technical systems up to social, economic, and ecological systems, where human or living beings play a crucial role.

The main research interest of Prof. I. Lubashevsky concerns the basic principles governing systems with motivation and the appropriate mathematical formalism required for their description. Systems with motivation comprise various statistical ensembles of elements with social behavior, human being or social animals, whose dynamics is impacted by memory effects, decision-making process, perception, recognition, prediction, and learning, in other words, by various stimuli motivating the system elements to behave in a particular way.

In FY2012 the research conducted by Prof. I. Lubashevsky was mainly focused on:

- analysis of the basic properties of human control over unstable systems based on mathematical modeling and hybrid human-computer experiments (in cooperation with Prof. S. Kanemoto);

- mathematical formalism required for modeling human decision-making near the perception threshold that is able to account for the bounded capacity of human cognition;
- effects of human intrinsic motivations on the decision-making and a mathematical formalism required for their modeling;

Among the results obtained during the reported period the following are worthy of noting.

1. A new approach in the theory of adaptation and exploration of unknown environment is proposed. Its key-point is the combination of the concepts of extrinsic and intrinsic motivations in human behavior, which is implemented in terms of the learning agent theory. A simple model combing the reinforcement learning concept and human curiosity/boredom is developed. It seems to be the first model predicting cyclic variations in human choice caused by its own properties rather than the agent interaction.
2. The development of the dynamical trap concept proposed previously has been continued. The dynamical trap is, for example, a certain neighborhood of a stationary point in the corresponding phase space wherein the motion of a system governed by a human operator is stagnated because the operator cannot recognized which point in this neighborhood is desired. During the reported period
    - it has been demonstrated that the model of oscillator with dynamical trap may be regarded as the generalization of the stationary point being the key notion in the theory of dynamical systems and the theory of emergent phenomena;
    - using the "lazy bead" model it was demonstrated that dynamical traps can cause new type non-equilibrium phase transitions with complex properties, for example, exhibiting on-off intermittency as well as the standard behavior of the 1-st order phase transitions;
    - the new concept of action dynamical trap was elaborated; it appeals to the notion of extended phase space in order to take into account active human behavior and, in this way, goes beyond the paradigms of Newtonian mechanics as well as the modern paradigm of human control.
3. Experiments on balancing virtual inverted pendulums with overdamped dynamics were continued (in collaboration with Prof. S. Kanemoto). In particular, it has been demonstrated that the corresponding phase portraits and

distribution functions look similar to ones generated by the model of oscillator with dynamical trap and are independent of the age, gender, skill of subjects as well as the difficulty of balancing. This result may be treated as the first experimental evidence for the concept of dynamical traps in human actions. The last experimental data also have posed a question about the significance of human memory in such actions and the hypothesis about the self-organized criticality as one of the main mechanisms affecting the dynamics of long-term human actions.

4. A next step is made toward the description of anomalous transport phenomena of the Lévy type. First, it has been demonstrated that the previously proposed Markov model with nonlinear noise is really able to describe Lévy flights. Second, a new Markov non-Newtonian model for Lvy random walks is developed, which is a novel candidate for simulating animal movement, e.g., in foraging or human travel patterns. Its pivot point is the introduction of a new phase variable similar to particle acceleration in order to describe the decision-making. In some sense it is a certain implementation of the general idea that modeling systems with essential human factor requires an extended phase space comprising objective and subjective components.

The research interests of Dr. I. Khmyrova involve the following area.

- Analytical study and modeling of optoelectronic devices, in particular, semiconductor light-emitting diodes with the patterned contacts.
- Models for calculation of electric potential created by the contacts with complicated configuration that are based on the conformal mapping technique. These models takes into account the fact that due to the patterned structure of the contacts current injected into the light-generating layer is spatially nonuniform along it.
- The model for calculation of the light extraction through the planar semiconductor-air interface.

The research interests of Prof. M. Ryzhii are in the following areas.

- Theory and computer modeling of graphene based optoelectronic devices.

  Among 3-, 2-, 1-, and 0-dimentional carbon structures, graphene layers, i.e., monolayers of carbon atoms forming a dense honeycomb two − dimensional

crystal structure, as well as non-Bernal stacked multiple graphene layers have attracted a considerable attention due to their unique features. In particular, such structures exhibit very specific optical properties associated with the gapless energy spectrum and linear dispersion law for electrons and holes. Due to a rather high quantum efficiency of interband transitions in a single graphene layer, graphene nanoribbons, and graphene bilayers, they are very promising for detectors of terahertz and infrared radiation. The utilization of structures based on the multiple graphene layers opens up the prospect of farther enhancement of capabilities of optical communication devices, in particular, THz and infrared photodetectors.

In FY 2012 we studied effects of plasma resonances on the characteristics of double graphene-layer optical modulators and detectors for THz and infrared wavelengths in cooperation with the group of Prof. T.Otsuji (RIEC, Tohoku University).

- Computer modeling of cardiac electrical activity.

  In FY2012 we worked on:

  - the development of heterogeneous oscillator model as a system of nonlinear differential equations with time delay coupling for simulation of the electrical dynamics of the human heart and possible effects of external electromagnetic radiation;
  - the development of models and software with reaction-diffusion approach for 3D heart modeling utilizing high-performance workstation.

External research grants received or being continued during the reported period

- "Extended Phase Space and Emergent Phenomena in Social Systems"

  JSPS "Grants-in-Aid for Scientific Research ” Program", Grant 2454041-00001, Duration: FY2012-FY2014 (in cooperation with Prof. Y. Watanabe)

- "Graphene on Silicon"

  Grant from JST-CREST, FY2010-FY2013 in cooperation with Prof. T.Otsuji, RIEC, Tohoku University.

Education activity

In FY2012:

1. A student team (including two 3rd-year students and four 4th-year students) whose research is aimed at modeling human behavior near the perception threshold has been created (under the supervision of Prof. I. Lubashevsky).

2. Under the cooperative supervision of Profs. S. Kanemoto and I. Lubashevsky two 4th-year students have defended their theses devoted to studying the fundamental regularities of human control based on human-computer experiments.

3. Under the supervision of. Prof. I. Khmyrova two 4th-year students have defended their theses.

4. One doctoral student continued his research work aimed at modeling human fuzzy rationality (under the supervision of Prof. I. Lubashevsky)

Member of laboratory taught the following courses:

Undergraduate courses:

F3 Discrete Systems;

P4 C++ Programing;

E8 Thesis Writing and Presentation;

NS7 Introduction to Optoelectronics;

S2 Electronics.

Graduate courses:

CSA17 Computer Simulation of Stochastic Processes (is expected to start in FY 2013);

SYA04 Optoelectronics. Computer and Communication Devices;

SYA07 Modeling of Advanced Devices;

SYA06 Advanced Devices for Computer and Communication Systems.

Refereed Journal Papers

[i-lubash-01:2012] Arkady Zgonnikov and Ihor Lubashevsky. Complex dynamics of multiparticle systems governed by bounded rationality. *Chaotic Modeling and Simulation*, (1):60–66, 2013.

We consider a system of interacting elements that mimic certain properties of human perception, namely, the bounded capacity of ordering events, actions, etc. according to their preference. Previously this feature was described by the notion of dynamical traps, which is modified in the present work in order to take into account the imperfectness of human perception of their own actions. Numerically we demonstrate that the considered system under the presence of dynamical traps of a new type exhibits complex dynamics, including highly irregular motion.

[i-lubash-02:2012] Ihor Lubashevsky and Dmitry Parfenov. Complex dynamics and phase transitions caused by fuzzy rationality. *Chaotic Modeling and Simulation*, (1):31–38, 2013.

The notion of dynamical traps is proposed to allow for effect caused by the bounded capacity of human cognition in ordering events or actions according to their preference. As a result, in the vicinity of an optimal behavior a decision-maker has no stimulus to change his current behavior. By way of example, one dimensional system of coupled oscillators with dynamical traps is studied numerically. The model assumes the dynamical traps to form a "low" dimensional region in the corresponding phase space where the system motion is stagnated. It is demonstrated that the dynamical traps and possible noise individually can cause the given system to exhibit complex dynamics and to undergo various phase transitions.

[i-lubash-03:2012] Ihor Lubashevsky. Dynamical traps caused by fuzzy rationality as a new emergence mechanism. *Advances in Complex Systems*, 15(8):1250045(1–25), 2012.

A new emergence mechanism related to the human fuzzy rationality is considered. It assumes that individuals (operators) governing the dynamics of a certain system try to follow an optimal strategy in controlling its motion but fail to do this perfectly because similar strategies are indistinguishable for them. The main attention is focused on the systems where the optimal dynamics implies the stability of a certain equilibrium point in the corresponding phase space. In such systems the fuzzy rationality gives rise to some neigh-

bourhood of the equilibrium point, the region of dynamical traps, wherein each point is regarded as an equilibrium one by the operators. So, when the system enters this region and while it is located in it, maybe for a long time, the operator control is suspended. To elucidate a question as to whether the dynamical traps on their own can cause emergent phenomena, the stochastic factors are eliminated from consideration. In this case the system can leave the dynamical trap region only because of the mismatch between actions of different operators. By way of example, a chain of oscillators with dynamical traps is analyzed numerically. As demonstrated, the dynamical traps do induce instability and complex behaviour of such systems.

[i-lubash-04:2012] Ihor Lubashevsky. Equivalent continuous and discrete realizations of Lévy flights: Model of one-dimensional motion of an inertial particle. *Physica A: Statistical Mechanics and its Applications*, 392(10):2323–2346, 2013.

The paper is devoted to the relationship between the continuous Markovian description of Lévy flights developed previously (*Lubashevsky et al., Phys. Rev. E* ***79*** *(2009) 011110,* ***80*** *(2009) 031148; Eur. Phys. J. B* ***78*** *(2010) 207,* ***82*** *(2011) 189*) and their equivalent representation in terms of discrete steps of a wandering particle, a certain generalization of continuous time random walks. the technique to be created, our consideration is confined to the one-dimensional model for continuous random motion of a particle with inertia. Its dynamics governed by stochastic self-acceleration is described as motion on the phase plane $\{x, v\}$ comprising the position x and velocity $v = dx/dt$ of the given particle. A notion of random walks inside a certain neighborhood $\mathcal{L}$ of the line $v = 0$ (the x-axis) and outside it is developed. It enables us to represent a continuous trajectory of particle motion on the plane $\{x, v\}$ as a collection of the corresponding discrete steps. Each of these steps matches one complete fragment of the velocity fluctuations originating and terminating at the "boundary" of $\mathcal{L}$. As demonstrated, the characteristic length of particle spatial displacement is mainly determined by velocity fluctuations with large amplitude, which endows the derived random walks along the x-axis with the characteristic properties of Lévy flights. developed classification of random trajectories a certain parameter-free core stochastic process is constructed. Its peculiarity is that all the characteristics of Lévy flights similar to the exponent of the Lévy scaling law are no more than the parameters of the corresponding transformation from the particle velocity v to the related variable of the core process. In this way the previously found validity of the continuous Markovian

model for all the regimes of Lévy flights is explained. Based on the obtained results an efficient "single-peak" approximation is constructed. In particular, it enables us to calculate the basic characteristics of Lévy flights using the probabilistic properties of extreme velocity fluctuations and the shape of the most probable trajectory of particle motion within such extreme fluctuations.

[khmyrova-01:2012] I. Khmyrova Yu. Kholopova E. Polushkin A. Kovalchuk V. Sirotkin A. Konishi, R. Yamase and S. Shapoval. Analytical modek of light-emitting diodes with patterned contact. *Optical Review*, 20(2):214–217, 2013.

In this paper we develop an analytical model for the light-emitting diode (LED) with the metal p-contact patterned as an array of thin strips. The model is based on conformal mapping approach and accounts for the overlapped fringing electric fields created by the adjacent strips. We derive analytical expressions for the electric potential, current injected into the LED active region and power of light extracted via the openings in the pattern. Spatial distribution of electric potential and LED radiation pattern are calculated.

[m-ryzhii-01:2012] T.Otsuji, S. Boubanga Tombet, A. Satou, M. Ryzhii, and V.Ryzhii. Terahertz-wave generation using graphene: Toward new types of terahertz lasers. *IEEE Journal of Selected Topics in Quantum Electronics*, 19(1):8400209(9), January-February 2013.

This paper reviews recent advances in terahertz-wave generation in graphene toward the creation of new types of terahertz lasers. First, fundamental basis of the optoelectronic properties of graphene is introduced. Second, nonequilibrium carrier relaxation and recombination dynamics in optically or electrically pumped graphene is described to introduce a possibility of negative dynamic conductivity in a wide terahertz range. Third, recent theoretical advances toward the creation of current-injection graphene terahertz lasers are described. Fourth, unique terahertz dynamics of the two-dimensional plasmons in graphene are described. Finally, the advantages of graphene materials and devices for terahertz-wave generation are summarized.

[m-ryzhii-02:2012] V.L. Semenenko, V.G. Leiman, A.V. Arsenin, V. Mitin, M. Ryzhii, T. Otsuji, and V. Ryzhii. Effect of self-consistent electric field on characteristics of graphene p-i-n tunneling transit-time diodes. *Journal of Applied Physics*, 113:024503(7), 2013.

We develop a device model for p-i-n tunneling transit-time diodes based on single- and multiple graphene layer structures operating at the reverse bias

voltages. The model of the graphene tunneling transit-time diode (GTUNNETT) accounts for the features of the interband tunneling generation of electrons and holes and their ballistic transport in the device i-section, as well as the effect of the self-consistent electric field associated with the charges of propagating electrons and holes. Using the developed model, we calculate the dc current-voltage characteristics and the small-signal ac frequency-dependent admittance as functions of the GTUNNETT structural parameters, in particular, the number of graphene layers and the dielectric constant of the surrounding media. It is shown that the admittance real part can be negative in a certain frequency range. As revealed, if the i-section somewhat shorter than one micrometer, this range corresponds to the terahertz frequencies. Due to the effect of the self-consistent electric field, the behavior of the GTUNNETT admittance in the range of its negativity of its real part is rather sensitive to the relation between the number of graphene layers and dielectric constant. The obtained results demonstrate that GTUNNETTs with optimized structure can be used in efficient terahertz oscillators.

[m-ryzhii-03:2012] T. Otsuji, T. Watanabe, S.A. Boubanga Tombet, A. Satou, W.M. Knap, V.V. Popov, M. Ryzhii, and V. Ryzhii. Emission and detection of terahertz radiation using two-dimensional electrons in III-V semiconductors and graphene. *IEEE Transactions on Terahertz Science and Technology*, 3(1):63–71, January 2013.

Recent advances in emission and detection of terahertz radiation using two-dimensional (2D) electron systems in III?V semiconductors and graphene are described. First the 2D plasmon resonance is presented to demonstrate intense broadband terahertz emission and detection from InGaP/InGaAs/GaAs and InAlAs/InGaAs/InP material systems. The device structure is based on a high-electron mobility transistor and incorporates the author ' s original asymmetrically interdigitated dual-grating gates. Second topic focuses on graphene, a monolayer carbon-atomic honeycomb lattice crystal, exhibiting peculiar carrier transport and optical properties owing to massless and gapless energy spectrum. Theoretical and experimental studies toward the creation of graphene terahertz injection lasers are described.

[m-ryzhii-04:2012] V. Ryzhii, T. Otsuji, M. Ryzhii, and M.S. Shur. Double graphene-layer plasma resonances terahertz detector. *Journal of Physics D: Applied Physics*, 45:302001(6), 2012.

We propose a detector of terahertz radiation based on a double graphene-layer heterostructure utilizing the tunnelling between graphene layers and the

resonant excitation of plasma oscillations (standing plasma waves). Using the developed device model, we substantiate the detector operation and calculate the spectral characteristics. It is shown that the detector responsivity exhibits the resonant peaks when the frequency of incoming terahertz radiation approaches the resonant plasma frequencies. These frequencies are tuned by the bias voltage. The height of the responsivity resonant peaks in sufficiently perfect double graphene-layer heterostructures can markedly exceed those in the resonant plasma?wave detectors based on the standard heterostructures and utilizing the plasma hydrodynamic nonlinearity.

[m-ryzhii-05:2012] V. Ryzhii, T. Otsuji, M. Ryzhii, V. G. Leiman, S.O. Yurchenko, V. Mitin, and M.S. Shur. Effect of plasma resonances on dynamic characteristics of double graphene-layer optical modulator. *Journal of Applied Physics*, 112:104507(7), 2012.

We analyze the dynamic operation of an optical modulator based on double graphene-layer (GL) structure utilizing the variation of the GL absorption due to the electrically controlled Pauli blocking effect. The developed device model yields the dependences of the modulation depth on the control voltage and the modulation frequency. The excitation of plasma oscillations in double-GL structure can result in the resonant increase of the modulation depth, when the modulation frequency approaches the plasma frequency, which corresponds to the terahertz frequency for the typical parameter values.

[m-ryzhii-06:2012] T. Otsuji, S. A. Boubanga Tombet, A. Satou, H. Fukidome, M. Suemitsu, E. Sano, V. Popov, M. Ryzhii, and V. Ryzhii. Graphene-based devices in terahertz science and technology. *Journal of Physics D: Applied Physics*, 45:303001(9), 2012.

Graphene is a one-atom-thick planar sheet of a honeycomb carbon crystal. Its gapless and linear energy spectra of electrons and holes lead to nontrivial features such as giant carrier mobility and broadband flat optical response. In this paper, recent advances in graphene-based devices in terahertz science and technology are reviewed. First, the fundamental basis of the optoelectronic properties of graphene is introduced. Second, synthesis and crystallographic characterization of graphene material are described, particularly focused on the authors ' original heteroepitaxial graphene-on-silicon technology. Third, nonequilibrium carrier relaxation and recombination dynamics in optically or electrically pumped graphene are described to introduce a possibility of negative-dynamic conductivity in a wide terahertz range. Fourth, recent

theoretical advances towards the creation of current-injection graphene terahertz lasers are described. Fifth, the unique terahertz dynamics of the two-dimensional plasmons in graphene are described. Finally, the advantages of graphene devices for terahertz applications are summarized.

Refereed Proceeding Papers

[i-lubash-05:2012] Arkady Zgonnikov Toru Miyazawa Daichi Taniguchi Ihor Lubashevsky, Shigeru Kanemoto. Dynamical Traps and Balancing of Overdamped Pendulums: Virtual Experiments and Universal Properties of Human Control. In J. Sasaki H. Fujita, M. Tuba, editor, *Proceedings of 2nd International Conference on Automatic Control, Soft Computing And Human-Machine Interaction (ASME '13, Morioka City, Iwate, Japan, April 23-25, 2013)*, Recent Advances in Electrical Engineering Series, vol 12., pages 185–190. WSEAS Press, 2013.

Experiments on the balancing of virtual pendulums of various forms were conducted to examine the basic features of human control over unstable systems. The experiments involved 10 human subjects of different age and skill. Three types of pendulums: an inverted stick, a triangular pendulum, and a vibrating spring were used. The collected experimental data are analyzed by constructing the phase portraits in the space "angle–angular velocity" and the distribution functions of the corresponding phase variables. It is demonstrated that actually only the dimensions of the phase space region wherein a given pendulum trajectory is located depend on the subject age and skill as well as the pendulum parameters determining the difficulty of the balancing. In contrast, the forms of the distribution functions are the same for all the subjects. Possible explanation of the found universality is given. The data of the virtual experiments are also compared to the results of numerical simulation of the so-called oscillator with dynamical traps studied previously. The phase trajectories and the phase variable distributions are shown to be similar for the two systems. Actually the latter result has encouraged us to apply the concept of dynamical traps to describing the basic features of human control, in particular, its fuzziness and discontinuity.

[i-lubash-06:2012] Arkady Zgonnikov and Ihor Lubashevsky. Complex dynamics of multiparticle system governed by bounded rationality. In *Proceedings of 5th Chaotic Modeling and Simulation International Conference, (CHAOS'12 12-15 June 2012, Athens Greece)*, pages 161–168, 2012.

For a generalized version of this work see the paper by A. Zgonnikov and I. Lubashevsky, (CMSIM 1: 60–66, 2013) noted in the present report.

[i-lubash-07:2012] Arkady Zgonnikov Toru Miyazawa Daichi Taniguchi Shigeru Kanemoto, Ihor Lubashevsky. Virtual Stick Balancing: Statistical Invariants of Human Response. In *Proceedins of 44th ISCIE International Symposium on Stochastic Systems Theory and Its Applications (SSS'12, Tokyo, November 1-2, 2012)*, pages 215–218. Institute of Systems, Control and Information Engineers (ISCIE), 2013.

Human behaviour during the process of virtual inverted pendulum balancing in viscous environment is analyzed. The results of the virtual experiments are compared to the results of previous studies on so called dynamical trap effect. It is shown that the phase trajectories and phase variables distributions of the virtual stick motion under human control are similar to those of an oscillator under the presence of noise described by the dynamical trap model. Moreover, it is discovered that the patterns of system dynamics under human control are similar for all feasible values of system parameters. We therefore suggest that the dynamical trap model could reflect certain features of human behaviour during processes of dynamical systems control near equilibrium points

[i-lubash-08:2012] Arkady Zgonnikov and Ihor Lubashevsky. Modeling humans perception of their own actions: the dynamical traps approach. In *Proceedins of 44th ISCIE International Symposium on Stochastic Systems Theory and Its Applications (SSS'12, Tokyo, Nov. 1-2, 2012)*, pages 40–43. Institute of Systems, Control and Information Engineers (ISCIE), 2013.

We consider the dynamical traps model of human fuzzy rationality which describes the behaviour of human controlling a dynamical system near an equilibrium point. The basic dynamical trap model describes the behaviour of human operator neglecting small deviations from the equilibrium point. We propose the extended model that takes into account the effect of imperfect implementation of the desired control strategy. The results of numerical simulations confirm that human fuzzy rationality could be responsible for anomalous behaviour of human-controlled systems.

[i-lubash-09:2012] Yoshinori Uchimura Ihor Lubashevsky, Kimiaki Saito. Lévy random walks as nonlinear Brownian motion. In *Proceedins of 44th ISCIE International Symposium on Stochastic Systems Theory and Its*

Applications (SSS'12, Tokyo, Nov. 1-2, 2012), pages 162–167. Institute of Systems, Control and Information Engineers (ISCIE), 2013.

For describing irregular movement of animals in random search as well as patterns of human travel during daily activity an original model of Brownian nonlinear motion is proposed. The wandering particle is represented as a point in the extended phase space comprising its position, velocity, and, in addition, the acceleration. The acceleration is assumed to be governed by a certain random process with stochastic self-acceleration. The acceleration dynamics is described by a nonlinear stochastic differential equation of the Hänggi-Klimontovich type. Its regular component represents the preference of the particle moving with a certain fixed velocity. The stochastic component with the noise intensity growing with the acceleration is related to the active behaviour of the wandering particle in changing the motion direction. The model is studied numerically. The obtained results allow us to state that the developed model generates motion trajectories that can be treated as Lévy random walks.

[i-lubash-10:2012] Arkady Zgonnikov and Ihor Lubashevsky. Choice oscillations caused by boredom effect in human learning model. In *Proceedings of 2012 IEEE International Conference on Systems, Man, and Cybernetics (SMC 2012, COEX, Seoul, Rep. of Korea, Oct. 14-17, 2012)*, pages 1785–1787. (IEEE Conf. Publ.), 2012.

We propose the dynamical model describing the effect of boredom in the human learning process. It is shown numerically that the instability may appear in the dynamics of the system corresponding to the simple case of the single agent performing repeated choice between two alternatives. The discovered patterns of the periodic preference oscillations confirm that the model under consideration could capture such interesting phenomenon of human behaviour as the boredom effect.

[i-lubash-11:2012] Ihor Lubashevsky and Dmitry Parfenov. Complex dynamics and phase transitions caused by fuzzy rationality. In *Proceedings of 5th Chaotic Modeling and Simulation International Conference, (CHAOS'12 12-15 June 2012, Athens Greece)*, pages 95–102, 2012.

For a generalized version of this work see the paper by I. Lubashevsky and D. Parfenov, (CMSIM 1: 31–38, 2013) noted in the present report.

[i-lubash-12:2012] Ihor Lubashevsky. Trajectory classification of random motion with stochastic self-acceleration and its anomalous properties. In Ch. Tsitouras Z. Anastassi T. E. Simos, G. Psihoyios, editor, *Proceedings of*

10th International Conference of Numerical Analysis and Applied Mathematics (ICNAAM 2012, Kos, Greece, 19–25 Sep. 2012), pages 2058–2061. AIP (Amer. Inst. Physics) Conf. Proc. Vol. 1479, 2012.

An original classification of random trajectories formed by a Brownian particle whose motion is governed by stochastic self-acceleration is constructed. In particular, it enables us to elucidate the mechanism endowing the analyzed continuous Markovian random walks with the characteristic properties of Lévy flights or Lévy walks. Lévy flights appear in the case when the particle velocity is governed by stochastic self-acceleration, Lévy walks are the case when the particle acceleration undergoes stochastic self-acceleration whereas the particle velocity is approximately fixed in magnitude.

[khmyrova-02:2012] I. Khmyrova Ju. Kholopova E.Polushkin A. Kovalchuk V. Sirotkin A. Konishi, R. Yamase and S. Shapoval. Improvement of the efficiency of light-emitting diodes by contact patterning. In *Techn. Dugest of 8th Int. Conf. on Optics-Photonics Design and Fabrication -ODF'12*, pages 239–240., St. Petersburg, Russia, Jul. 2012.

Analytical model is developed for LED with a patterned contact to calculate electric field distribution along active region, current injected into it and evaluate light extracted via openings in the grating.

[khmyrova-03:2012] R. Yamase A. Kovalchuk E.Polushkin V. Zemlyakov S. Shapoval Ju. Kholopova, A. Konishi and I. Khmyrova. Analysis of light-emitting diode with patterned contact by conformal mapping technique. In *32nd Progress in Electromagnetics Research Symposium -PIERS 2012*, page 407, Moscow, Russia, Aug. 2012.

An analytical model for the LED with a p-contact patterned as an array of narrow strips is developed. It is demonstrated that the effect of the contact patterning is twofold: (1) at properly chosen strip separation and bias voltage light can be generated even in the parts of the active region not covered by the contact strips; and (2) light can be extracted via the openings between the strips.

[khmyrova-04:2012] R. Yamase E.Polushkin A. Kovalchuk V. Zemlyakov S. Shapoval A. Konishi, Ju. Kholopova and I. Khmyrova. AlGaN/InGaN/GaN LED with Patterned Contact: Analysis of Efficiency Improvement. In *Abstr. Book of the Int. Workshop on Nitride Semiconductors - IWN 2012*, pages TuP–OD–2, p.245, Sapporo, Japan, Oct. 2012.

In this paper we study the impact of LED contact patterning on the light extraction. We demonstrate that the enhanced light emission in the LED with the patterned p-contact can be attributed to the possible current injection into the uncovered portions of the active region, generation of light there and its extraction via the openings in the patterned contact.

[khmyrova-05:2012] N. Watanabe T. Maeda I. Khmyrova, A. Konishi and E. Shestakova. Analysis of resonant mass sensor with nanotube- or nanowire-array over two-dimensional electron gas. In *26th European Conf. on Solid-State Transducers - EUROSENSORS2012,*, pages PT4–4, Krakow, Poland, Sept. 2012.

This paper addresses a resonant sensor in which current flowing along the channel created at the semiconductor heterojunction between source and drain contacts is controlled by array of oscillating micromachined cantilevers. Mechanical oscillations of each cantilever are directly transduced into variable electric current, We develop simple analytical model accounting for the impact of fringing electric field on sheet electron density in the channel. Spatially nonuniform sheet electron density distribution results in distributed resistance of the channel. Calculating resistance we derived an expression for the amplitude of the frequency-dependent component of the source-drain current in the presence of fringing and compared it with that given by the ideal model.

[m-ryzhii-07:2012] M. Ryzhii, T. Otsuji, S. Yurchenko, N. Ryabova, V. Ryzhii, and M.S. Shur. Plasma effects in graphene-based electro-optical modulators. In *The 32nd Progress in Electromagnetics Research Symposium (PIERS 2012)*, Moscow, Russia, August 2012. The Electromagnecits Academy.

We developed device models for electro-optical modulators based on gated single- and multiple-graphene-layer structures as well as in gateless double graphene-layer structures exploiting the electrically-controlled Pauli blocking effect and operating in different ranges of radiation spectrum.

[m-ryzhii-08:2012] M. Ryzhii, V. Ryzhii, N.V. Baryshnikov, V.E. Karasik, and T. Otsuji. Interband detectors of terahertz and infrared radiation based on graphene p-i-n structures. In *The 31st Progress in Electromagnetics Research Symposium (PIERS 2012)*, Kuala Lumpur, Malaysia, March 2012. The Electromagnecits Academy.

In this communication, we consider the concepts of THz/IR photodetectors utilizing multiple graphene layers (MGL) and graphene nanoribbons (GNR)

structures: the MGL p-i-n photodiode considered previously, and the newly proposed GNR p-i-n photodiode.

Unrefereed Papers

[i-lubash-13:2012] Ihor Lubashevsky and Shigeru Kanemoto. Stationary point generalization for social system dynamics. In *Proceedings of 4th Workshop on Inverse Problems and Applications on Medical Science and Engineering (Tokyo, Dec. 1-2, 2012)*, pages 59–63. Institute of Statistical Mathematics, Cooperative Research Report 291, 2013.

A new concept of dynamical traps required to model human behavior is considered. It assumes that individuals (operators) governing the dynamics of a certain system try to follow an optimal strategy in controlling its motion but fail to do this perfectly because similar strategies are indistinguishable for them. The main attention is focused on the systems where the optimal dynamics implies the stability of a certain equilibrium point in the corresponding phase space. In such systems the bounded capacity of human cognition gives rise to some neighborhood of the equilibrium point, the region of dynamical traps, wherein each point is regarded as an equilibrium one by the operators. So when a system enters this region and while it is located in it, maybe for a long time, the operator control is suspended. The present work draws on the results obtained previously as well as new ones and is mainly aimed at elucidating the basic principles in constructing a mathematical formalism describing this human feature. In particular, it is demonstrated that oscillator with dynamical traps can be derived within rather general assumptions about human behavior. In addition it is demonstrated the notion of dynamical traps is applicable to describing human control over an unstable system. The results of experiments on balancing a virtual over damped pendulum are present to justify this statement.

Grants

[i-lubash-14:2012] Ihor Lubashevsky and Yodai Watanabe. Extended Phase Space and Emergent Phenomena in Social Systems, 2012-2014.

JSPS “Grants-in-Aid for Scientific Research” Program, Grant 24540410-0001. The research is aimed at elucidating the mathematical formalism required for modelling social systems.

[m-ryzhii-09:2012] M. Ryzhii. Co-investigator on the project 'Graphene on Silicon (GOS)' supported by Japan Science and Technology Agency, CREST, 2010-2013.

Academic Activities

[khmyrova-06:2012] I. Khmyrova, 2012.

Senior member

[khmyrova-07:2012] I. Khmyrova, 2012.

Member

[khmyrova-08:2012] I. Khmyrova, 2012.

Member

[m-ryzhii-10:2012] M. Ryzhii.

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[m-ryzhii-12:2012] M. Ryzhii, July 1995.

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[m-ryzhii-13:2012] M. Ryzhii, Dec. 1996-present.

Senior Member

Ph.D and Others Theses

[i-lubash-15:2012] Toru Miyazawa. Statistical Invariants of Human Response: Virtual Experiments on Stick Balancing, Undergradute School, 2013.

Balancing virtual sticks of various forms is used to examine the basic features of human control over unstable systems. Experiments with 10 persons different in age and skills and three kinds of stick balancing simulation models are performed. The collected experimental data are analyzed by constructing the corresponding phase portraits and the distributions of phase variables. It is found that actually only the amplitude of the phase trajectories is affected by

the age and skill of the participants and the stick parameters determining the difficulty of the balancing. In contrast, the form of the distribution functions is the same for all the participants. Possible explanation of the found universality is discussed.

Supervision in cooperation with Profs. S. Kanemoto and I. Lubashevsky

[i-lubash-16:2012] Daichi Taniguchi. Virtual simulator for stick balancing, Undergradute School, 2013.

The present research is aimed at developing a virtual experiment methodology using real time human-computer hybrid simulation. We develop three different kinds of simulation models for stick balancing to study the simple examples of human- controlled system. These models are a simple inverted stick, a triangle, and a vibrating spring. These models enable us to investigate what kinds of information humans focus on when they control unstable systems. We pay attention to two issues in developing a real time human-computer hybrid simulator. The first one is the requirement for high-precision time discretization of sampling. The second one is proper handling of controlling devices, including obtaining correct mouse position for human operation and preventing screen flickering during the stick motion. The use of this simulator in conducted virtual experiments proved that the developed real time hybrid simulator demonstrates the acceptable performance for these purposes.

Supervision in cooperation with Profs. S. Kanemoto and I. Lubashevsky

[khmyrova-09:2012] Satoru Tomioka. Gradiation thesis, School of Computer Science and Engineering, 2012.

Thesis Advisor: I.Khmyrova

[khmyrova-10:2012] Taichi Hasegawa. Graduation thesis, School of Computer Science and Engineering, 2012.

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Others

[i-lubash-17:2012] Arkady Zgonnikov and Ihor Lubashevsky. Human fuzzy control: action dynamical trap model. e-print arXiv:1212.2717[nlin.AO], Dec. 12 2012.

Summary of Achievement

We consider a general problem related to the mathematical description of human fuzzy rationality. Human operators controlling dynamical systems are often incapable of precisely identifying and implementing the desired control strategy. The operator of a dynamical system treats the current value of the control effort as acceptable if it deviates insignificantly from the desired, or optimal value. The operator starts correcting the actions only when she identifies that this deviation has become considerably large. We propose a non-Newtonian model capturing the operator fuzzy perception of her own actions based on the previously introduced dynamical trap concept. It deals with the physical phase space of a controlled system extended with an independent phase variable characterizing the operator motivated actions. The properties of the model are illustrated via the simple example of an oscillator with action dynamical trap.

Submitted to Physical Review E.