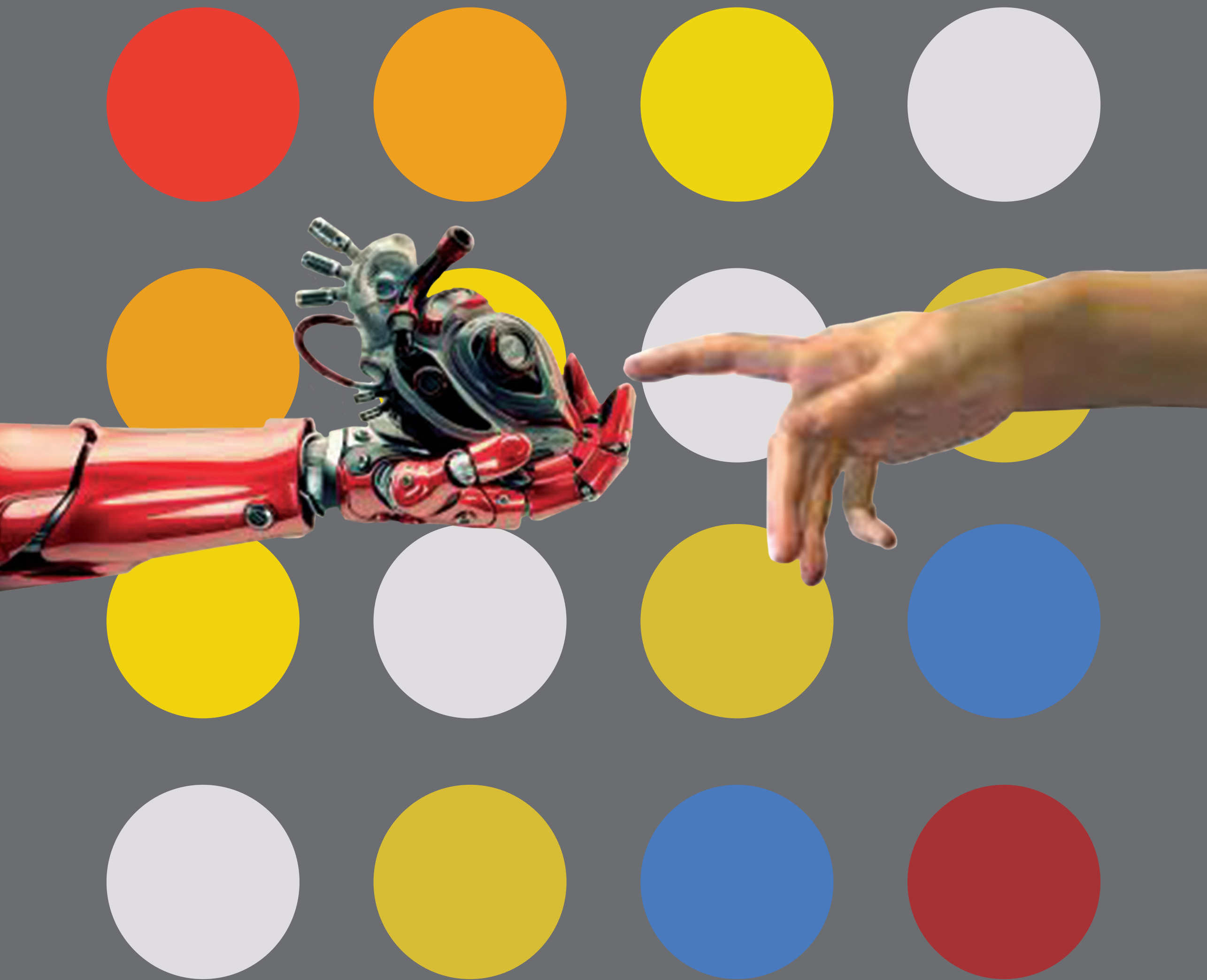
SERBIAN ACADEMY OF SCIENCES AND ARTS

WHERE THE ENGINEERING AND NATURE MEET: 100 YEARS FROM THE BIRTH OF RAJKO TOMOVIĆ

ТАМО ГДЕ СЕ САСТАЈУ ИНЖЕЊЕРИНГ И ПРИРОДА: 100 ГОДИНА ОД РОЂЕЊА РАЈКА ТОМОВИЋА



NOVEMBER 1, 2019, SASA GRAND HALL, KNEZA MIHAILA 35/II, BELGRADE

ORGANIZING COMMITTEE:

Dejan Popović,
SASA**,** president of ETRAN, member of SASA (chair)
Srđan Stanković,
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Aleksandra Hreljac (SASA)
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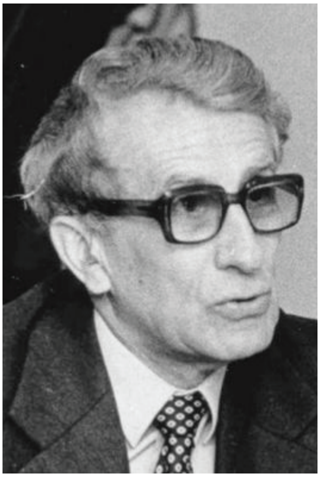
Time: Friday, November 1, 9:00-17:30
Registration: 9:00 to 9:30
Location: Serbian Academy of Sciences and Art (SASA), Kneza Mihaila 35/II, Belgrade, Serbia

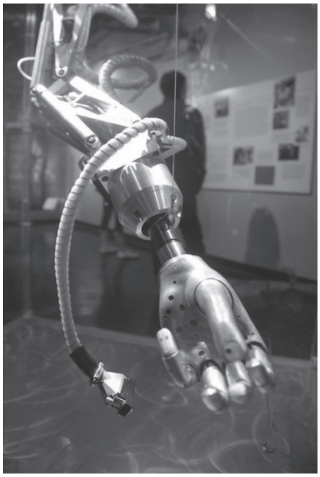
The Conference is organized by the Serbian Academy of Sciences and Arts (SASA), Belgrade and the Society for Electronics, telecommunication, computers, automation and nuclear engineering (ETRAN), Belgrade, Serbia.

An exhibition in the Gallery in the SASA building is running in parallel (opening on the October 14). The participants' collective visit, with the opening remarks by Dejan Popović is scheduled for the Thursday, October 31 at 18:30. The exhibition comprises the innovations and systems contributed by Tomović and his colleagues.

International Conference

WHERE THE ENGINEERING AND NATURE MEET: 100 YEARS FROM THE BIRTH OF RAJKO TOMOVIĆ





NOVEMBER 1, 2019, SASA GRAND HALL, KNEZA MIHAILA 35/II, BELGRADE

PROG

09:30- 09:45 OPENING SESSION

09:30 **Zoran Lj. Petrović, Opening of the Conference**
Secretary of the Department of Technical Sciences of Serbian Academy of Sciences and Arts (SASA), Belgrade, Serbia

09:45 **Dejan Popović, Welcome message**
Member of SASA

10:00-11:00 NEUROENGINEEINRG – PART 1

10:00-10:30 **Dejan Popović**
Member of SASA, Belgrade, Serbia
COULD WE REPLICATE BIOLOGICAL CONTROL OF THE LOCOMOTION IN HUMAN-MADE SYSTEMS

10:30-11:00 **Andrea d'Avella**
Department of Biomedical and Dental Sciences and Morphofunctional Imaging, University of Messina, Italy and Laboratory of Neuromotor Physiology, IRCCS Santa Lucia Foundation, Rome, Italy
NEW PERSPECTIVES ON THE NEURAL CONTROL OF MOVEMENT

Coffee break 30 minutes

11:30-13:30 NEUROENGINEERING – PART 2

11:30-12:00 **Michael A. Nitsche**
Department of Clinical Neurophysiology, Georg-August-University, Göttingen, Germany
OPTIMAL TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS)

12:00-12:30 **Igor M. Nikolić**
Clinical Center of Serbia, Clinic of Neurosurgery, Belgrade, Serbia
INVASIVE NEUROMODULATION IN TREATMENT OF PAIN AND SPASTICITY

GRAM

12:30-13:00	**Natalie Mrachacz-Kersting** *Department of Health Sciences and Technology, Aalborg University, Aalborg, Denmark* **INDUCTION OF NEURAL PLASTICITY IN HUMANS**
13:00-13:30	**Ina Tarkka** *Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland* **STUDIES ON SENSORIMOTOR CONTROL USING MEG**
13:30-14:30	**LUNCH – Club of the Serbian Academy of Sciences and Arts**
15:00-17:10	**THE INSPIRATION STARTED WITH RAJKO TOMOVIĆ**
15:00-15:30	**Tadej Bajd** *President of the Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia* **THE ROLE OF THE BELGRADE - LJUBLJANA LINK IN THE ROBOTICS AND BIOENGINEERING WORLDWIDE**
15:30-16:00	**Srđan Stanković** *Vlatacom Institute and University of Belgrade, Faculty of Electrical Engineering, Serbia* **ARTIFICIAL INTELLIGENCE**
16:00-16:30	**Srbijanka Turajlić** *University of Belgrade, Belgrade, Serbia* **HOW I MET ACADEMICIAN RAJKO TOMOVIĆ**
16:30-17:00	**Veljko Potkonjak** *University Metropolitan, Belgrade, Serbia* **BELGRADE SCHOOL OF ROBOTICS: WHY AND HOW?**
17:00	**Dejan Popović – Closing remarks**

COULD WE REPLICATE BIOLOGICAL CONTROL OF THE LOCOMOTION IN HUMAN-MADE SYSTEMS

Dejan Popović,
Member of SASA, Belgrade, Serbia
and Professor emeritus, Aalborg University, Denmark

Abstract: We present the notion of the "cybernetic actuator" in the context of bioengineering and neurophysiology introduced by academician Rajko Tomović. Since the earliest discussions of human movement, it has always been acknowledged that sensory input is essential for coordinated control. One can hypothesize that a movement, no matter how complex, can be broken down into reflexes (elementary sensorimotor reactions). In terms of computer science, this model refers to an organization of the stored facts such that algorithmically described reasoning processes can be implemented. The transfer of the control to the machine comprises two tasks: 1) the facts about a specific knowledge domain must be encoded in the form suitable for algorithmic processing, and 2) the envisioned process must be presented in an algorithmic form. Rajko Tomović suggested that the formalism of production rules is applicable for the transfer of biological control to machines. A production rule is a situation - action couple, meaning that whenever a particular situation is encountered, given as the left side of the rule, the action on the right side of the rule is performed. There is no a priori constraint on the form of the situation or of the action. A system based on production rules usually have three components: the rule base, consisting of the set of production rules, one or more data structures containing the known facts relevant to the domain of interest, possibly also some useful definitions; these are often called facts, and the interpreter of these facts and rules, which is the mechanism that decides which rule to apply and initiates the corresponding action. It is a fundamental principle of rule-based programming that each rule is an independent item of knowledge, containing all the conditions required for an application. There is no mechanism anywhere else except in the rule itself that creates conditions that could prevent it from being executed. The other principle is that the rules are orthogonal; hence, only the interpreter knows how to connect them. In a production rule system, the rules are not ordered, and they can be activated at any moment. Because of this modularity, such a system can be easily modified because the addition, deletion, or modification of a rule does not affect the architectural structure of the program. A feature of the production rule system is the ability to look first at the established facts and to proceed forward (forward chaining) or to start from the aims and proceed backward, i.e., from the action part of the rules (backward chaining). Neither method has shown a clear advantage over the other as far as overall efficiency is concerned. The forward method provides better control over the order in which we acquire data that may possibly satisfy the optimization criteria. The backward method is better in that it enables the interpreter to get closer to the tasks it tries to reach, as it can apply only those rules which are relevant to the specific tasks. The example selected for illustrating the method is a powered artificial leg that is integrated at the subconscious level and fully adapts to the environment.

NEW PERSPECTIVES ON THE NEURAL CONTROL OF MOVEMENT

Andrea d'Avella,

Department of Biomedical and Dental Sciences and Morphofunctional Imaging, University of Messina, Italy and Laboratory of Neuromotor Physiology, IRCCS Santa Lucia Foundation, Rome, Italy

Abstract: The control of movement, from daily living actions to sophisticated motor skills in sports and tool manipulation, requires coordinating many muscles and mastering the complex dynamics of multiarticular limbs. Decades of neurophysiological and behavioral investigations have provided a comprehensive knowledge of the neural mechanisms and control strategies underlying motor control. However, a full understanding of the functional organization of the human motor system is still missing. A long-standing hypothesis is that the CNS relies on muscle synergies, coordinated activations of groups of muscles, to efficiently control movements. Muscle synergies, extracted from multi-muscle EMG recordings using multidimensional decomposition algorithms such as non-negative matrix factorization, capture regularities in the spatial, temporal, and spatiotemporal organization of the muscle patterns and may simplify control by providing a low-dimensional representation of the motor commands. In the last two decades a growing number of studies investigating many different motor tasks have shown that muscle patterns are generated as combinations of a small number of muscle synergies. Stronger evidence for muscle synergies has come from testing the prediction that, if muscle synergies are organized by the CNS, they must affect the difficulty in learning or adapting motor skills. Using myoelectric control in a virtual manipulation environment, it has been possible to alter the mapping between muscle activation and hand force -as in a surgical re-arrangement of the tendons- and to show that it is harder to adapt to virtual surgeries that require new or modified synergies than to adapt to virtual surgeries that can be compensated by recombining existing synergies. Moreover, extended practice after a virtual surgery allows to investigate whether different individuals rely on the same motor learning processes and converge onto a unique, possibly optimal control strategy. In all participants practicing a single experimental session with a virtual surgery that is incompatible with existing synergies performance does not improve, suggesting that synergy learning is a slow adaptive process distinct from the fast process involved in compensating a perturbation through recombination of existing synergies. In contrast, after multiple practice sessions there are large inter-individual differences in performance, suggesting different synergy learning abilities. Finally, individual changes in muscle synergy organization and synergy re-learning capabilities after neurological lesions may lead to novel diagnostic tools and personalized rehabilitation interventions.

OPTIMAL TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS)

Michael A. Nitsche,
Leibniz Research Center for Work Environment and Human Factors at TU Dortmund, Dept. Psychology and Neurosciences, Göttingen, Germany

Abstract: tDCS is a non-invasive brain stimulation protocol with the potential to induce excitability alterations, including neuroplasticity, in the human brain, and has shown potential not only in basic physiological, and cognitive studies, but also as promising therapeutic agent in numerous neurological, and psychiatric diseases. Most of the clinical pilot studies so far were however proof of principle studies, which showed efficacy of this intervention, but were not designed to induce maximal effects. The latter requires systematic exploration of stimulation parameters, as well as combined approaches, e.g. with pharmacological, or behavioral interventions. In this talk, an overview of respective optimized protocols in these domains will be given. The respective study results suggest that an enhancement of efficacy of tDCS is possible, but follows not always simple linear rules, in accordance with the neuromodulatory role of this intervention.

INVASIVE NEUROMODULATION IN TREATMENT OF PAIN AND SPASTICITY

Igor M. Nikolić,
Clinical Center of Serbia, Clinic of Neurosurgery, Belgrade, Serbia

Abstract: Invasive chemical and electrical neuromodulations are modalities to treat the pain and spasticity. Neuromodulation does not eliminate the sources of pain and spasticity, but it modifies how the brain perceives the modified afferent input. The level of the reduction of pain and spasticity subjected to neuromodulation varies from patient to patient. Even a tiny amount of symptom reduction could be substantial if it allows patients to perform daily activities and reduces the amount of pain and spasticity medication intake. Chemical neuromodulation is the direct-controlled drug delivery into intradural space through a system of catheters and an implanted pump. The pump is delivering one of the following medications: baclofen, morphine, zyconotide, and others. The indications for this modality of treatment are the insufficiency of conventional pharmaco-therapy of spasticity, intolerable pain, and patients who cannot tolerate the side effects of the higher-dose of oral medications. The intradural neuromodulation is used for the diffused cancer pain, spasticity, failed back syndrome (FBS), complex regional pain syndrome (CRPS) type I and II. Spinal cord stimulation (SCS) uses modern implantable technology to deliver long-term electrical stimulation to the selected areas of the spinal cord. The electrodes are implanted into the epidural space of the spinal column. Stimulation activates the dorsal columns of the spinal cord and blocks the transmission of painful stimuli via the spinothalamic tracts to the brain. The exact

mechanism of action is still under investigation, but probably involves some combinations of neurohumoral (i.e., endorphin), antidromic stimulation of a spinal pain "gate," and supra-spinal center stimulation. GABA and serotonin levels have been shown to be increased with SCS. SCS may be an option when oral pain medications provide inadequate pain relief or intolerable side effects. It could be an alternative to permanent neuro-destructive procedures. Based on clinical experience and available evidence of effectiveness the indications are at this point the following: failed back syndrome (FBS) or low back syndrome or failed back, radicular pain syndrome or radiculopathies resulting in pain secondary to FBS, complex regional pain syndrome (CRPS) type I and II, reflex sympathetic dystrophy (RSD) and ischemic pain conditions due to occlusive or vasospastic arterial disease (lower extremity claudication and intractable, refractory angina pectoris). Generally, it is not used for cancer pain or patients with limited life expectancy.

INDUCTION OF NEURAL PLASTICITY IN HUMANS

Natalie Mrachacz-Kersting,
Faculty of Information Technology, University of Applied Sciences and Arts, Dortmund, Germany

Abstract: Brain-Computer Interfaces (BCIs) have emerged as a promising tool for the restoration and replacement of lost motor function in patient populations. A variety of control signals have been extracted from the ongoing electroencephalographic (EEG signal) both in the frequency and time domain. In this talk I will present the approach we have taken from the basic idea and the underlying neurophysiology to the final BCI tested in clinical populations. I will demonstrate why knowledge of the mechanisms behind memory and learning is vital for the development of rehabilitation technology, specifically BCIs, and further how factors such as plasticity induction, fatigue or even tremor may greatly impact on the system accuracy.

STUDIES ON SENSORIMOTOR CONTROL USING *MEG*

Ina M. Tarkka,
PhD, adjunct prof, Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

Abstract: Background: Magnetoencephalography (MEG) is a sister brain imaging technique to electroencephalography (EEG). It measures weak magnetic fields produced by neuronal currents. Magnetic fields are detected outside the head by superconducting quantum interference device (SQUID) sensors. We utilize a modern MEG (Elekta Neuromag®, Triux™) with 306 SQUID sensors arranged in a helmet-shaped device to cover the whole skull. Its benefits include high temporal resolution, passive and silent recording, non-invasive and easy preparation for measurement and furthermore, it does not require contact or effort from the subject.

Aim: We employ MEG in our sensorimotor control research. Specifically we are interested in early, precognitive phases in cortical function in the detection of peripheral somatosensory and nociceptive stimuli and furthermore, in early phases of voluntary movement control in healthy adults.

Methods: Eye movements, blinks and head position are recorded for preprocessing purposes, and a number of points around the scalp and nose are used to register individual head shape prior to MEG recording. We use transcutaneous innocuous electrical and pneumatic tactile stimuli and intracutaneous nociceptive electrical stimuli to hands, and controlled voluntary movement tasks. Preprocessing of data involves signal space separation (SSS) to reduce external artifacts and further sensor- and source-level preprocessing and analysis is performed with SPM12 and Brainstorm software packages.

Results: We have shown that electrical and tactile stimulation elicit somatosensory mismatch response with differences in activations in SI and SII cortices. Also source activities in somatosensory cortices depend on whether mixed, sensory or predominantly slower pain-responsive nerves are stimulated. Furthermore, we compared movement-related fields between self-paced and reaction-time movements showing differences in their source activations in MI and SI cortices.

Conclusions: MEG has provided accurate high-quality data allowing detailed analysis of the functions in primary motor, primary and secondary somatosensory and posterior insular cortices. It is a useful tool both in basic research in neurophysiology and in clinical applications.

References:
Hautasaari, P., et al. *Journal of Neuroscience* Methods 2019, 311:331-337.
Hautasaari, P., et l. *European Journal of Neuroscience* 2018, May 15.
Hautasaari, P., et al., *Neuroscience* (in revision)
Tarkka, I. M. & Hautasaari, P. *American Journal of Physical Medicine and Rehabilitation* 2019, 98(9):771-776.

THE ROLE OF THE BELGRADE - LJUBLJANA LINK IN THE ROBOTICS AND BIOENGINEERING WORLDWIDE

Tadej Bajd,
President of the Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia

Abstract: Mihajlo Pupin can be considered the first example of Serbian-Slovenian friendship from the field of engineering. He had a favourite Slovenian teacher already in Idvor and helpful Slovenian friend later in New York. He returned this favour when, being a close friend to US President Woodrow Wilson, he achieved during the Paris Peace Conference after the First World War that the Slovenian jewel, Lake Bled, remained a part of the Slovenian territory.

In my lifetime, an excellent example of the fruitful cooperation between Ljubljana and Belgrade scientists was demonstrated at the conference *Movement in Man and Machine*. The event was organized in 1982 in Portorož by the National Academy of Sciences, USA and the Council of Yugoslav Academies. The most eminent American roboticists and bioengineers were there. Our side was represented by three strong groups: medical robotics headed by Rajko Tomović, functional electrical stimulation by Lojze Vodovnik, and robot manipulators by Miomir Vukobratović.

The Belgrade hand, developed by Rajko Tomović, was the first multi-fingered, EMG controlled prosthesis worldwide, having the ability of automatic adaptation of the fingers to the shape of object grasped. Tomović had paid special attention to the initial phase of grasping. He quoted that the pre-shaping of the hand is determined by the shape of geometric primitives rather than by details of the target contour. Tomović' work served as an inspiration for our research in Ljubljana. We defined a new concept of estimating hand pre-shaping either in rehabilitation engineering or robotics. We defined the pentagon surface area determined by the tips of five fingers and the angle between the pentagon and object normal as the parameters estimating the pre-shaping phase of grasping.

The Pendulum test represents a simple but efficient modality to assess skeletal muscle spasticity in the clinical environment. Together with Vodovnik, we defined the relevant parameters for objective evaluation from the joint goniogram and EMG activity. The paper, we had published is my most frequently cited paper. This research was continued by Dejan Popović and his colleagues. They succeeded to distinguish very efficiently between extension and flexion spasticity by evaluation the difference between the positive and negative areas below the goniogram.

Tomović and Vukobratović were both guest professors at the Faculty of Electrical Engineering of the University of Ljubljana. Tomovič's lectures encompassed nonlinear systems, while Vukobratović presented robot dynamics. Vukobratovič's lectures can also be considered as the beginning of teaching robotics in Ljubljana. Vukobratović and colleagues were authors of many robotic textbooks written both in Serbian and English. We followed them by publishing a series of robotic textbooks in Slovenian and English, respectively.

Good collaboration is also characteristic for the Slovenian and Serbian Academy of Sciences and Arts which have the same English abbreviation SASA. Academy members are often invited to lecture at the events organized by either of the academies. An important task of the Slovenian Academy is also to publish books about the life and work of important deceased members. Recently, the book entitled *Lojze Vodovnik, Scientist and Humanist, 1933-2000* was published. It includes many descriptions of collaboration between Ljubljana and Belgrade in the area of biomedical engineering.

Let me conclude this presentation with the words written by Rajko Tomović into my memorial book at our country house:"The value of our cooperation is not only in our scientific contacts but also in developing reach human relations".

ARTIFICIAL INTELLIGENCE

Srđan Stanković,
Vlatacom Institute and University of Belgrade, Faculty of Electrical Engineering, Serbia

Abstract: Respect for tradition has never been deeply in the veins of the Serbian people. The meeting devoted to Professor Rajko Tomovič, one of the founders of the Department for Automatic Control at the Faculty of Electrical Engineering, University of Belgrade, Serbia, represents one of very rare and very positive exceptions.

Memories of Professor Tomović will, undoubtedly, shed new light to his complex multifaceted personality, helping us today to better understand the very basic principles of education and research, to make better distinction between the essence and the form in science and to take his huge intellectual curiosity as an inspiration for our own endeavors. I am persuaded that his broad insatiable interests for science, education, art, social life, sports can serve as good reference point for all those who pretend to be members of an intellectual elite.

Moreover, recollecting a large scope of his highly valuable achievements in diverse domains of science and technology will represent, besides their importance *per se*, a good checking point for our own current preoccupations in research. This is especially relevant for the academic community of Serbia, which has been, generally speaking, hibernated for a long time, while the world made huge steps forward.

My intention is to try to recollect, at the first place, his activities in the domain of artificial intelligence. Professor Tomović, aware of the importance of AI already decades ago, brought the most important world scientists to his summer school and gave us an opportunity to pick up the main ideas and concepts from the very source. As a founder of numerous projects in the domain of AI in Serbia (optical character reading, pattern recognition, AI in control and robotics), he did not hesitate to be in his office once a week during many years for the only purpose to be at the disposal of all those who would like to exchange thought about this challenging topic. One should not forget that he was one of the initiators of the IEEE Sponsored International Symposium NEUREL, held at the Faculty of Electrical Engineering, Belgrade, devoted to artificial neural networks, which celebrates next year its 30th anniversary.

In addition, I am going to present some details related to our common attempt to apply the concept of hybrid systems, very new at that time, to gait control and to try to draw new theoretical insights.

At the end, I will try to provide a picture of Professor Tomović as a University teacher through our common efforts to establish a modern concept of the course Nonlinear Control Systems. His unusual way of approaching teaching activities, oriented towards the very essence of knowledge the students have to acquire at the University, could be a good incentive for new restructurings of the Higher Education system in Serbia.

BELGRADE SCHOOL OF ROBOTICS: WHY AND HOW?

Veljko Potkonjak,
University Metropolitan, Belgrade, Serbia

Abstract: Belgrade School of Robotics is common name for something that started in sixties of the last century and still lasts. It has never been an institution or a formalized project, but rather a movement. Surprisingly and unexpectedly this movement born and grown in a small and relatively poor country managed to earned position among leaders in an extremely advanced and promising field of science. The field was robotics in its most advanced appearance - biologically inspired robotics. One may even say that the topics initiated and elaborated in the Belgrade School of Robotics often came too early to be fully understood and implemented. The School became a generator, a nursery of new ideas which later found their elaboration in research centers worldwide.

This entire movement was driven by creativity and enthusiasm of the two leaders, Rajko Tomović and Miomir Vukobratović, and the contributions of a number of most talented students who joined the School for some time or forever. Belgrade School of Robotics showed something important - “small can beat the big”. This is another reason why the phenomenon of the School should be considered rather instructive and encouraging. The scientific society in general could learn something from rereading the story about the School. In the past years, the researchers from rich countries often asked a fundamental question: “How was it possible that such advanced research was done regardless of restrictions in important prerequisites (missing high budget, not many doctoral students available, lack of proper support from the state and industry). The clear and convincing answer is still lacking. The current discussion intends to give the answer, or at least, to bring readers closer to the final understanding. The answer cannot be simple - it needs to elaborate several dilemmas.

The dilemmas that will be elaborated in this presentation are: 1) What was the social environment where Belgrade School of Robotics appeared and grew; 2) How topics for research were selected; 3) Who were the key researchers, the leaders (educational background, degrees, positions held) and what were their directions of research; 4) Relations within the School: personal characters of leaders and how they influenced the relations; and 5) How the research secured that by now we have three generations of distinguished scientists in the field of robotics.

GROWING UP WITH PROFESSOR TOMOVIĆ

Srbijanka Turajlić,
TERI engineering, Belgrade, Serbia

Abstract: Looking back, I think that professionally speaking it was pure luck that my first job was as assistant at the Department of control, at the Faculty of Electrical Engineering, where Professor Tomović was the Department chair. At that time he was renowned for his contribution to the development of the first computer, and later for the Belgrade hand, which many referred to as simply „Rajko's hand".

Freshly-graduated, armed with facts and proud of the knowledge I had acquired at university I hoped that I would be able to live up to the expectations of someone of his stature, and couldn't wait to get the opportunity to display all that I had learned. So it was no small surprise when, every time we started to discuss some problem, he refused to go into theoretical details, but instead kept asking simple questions „why…", „how…" „when…". It took me some time to finally learn the difference between knowing and understanding, and to find out where creativity actually stems from.

The other important lesson I learned from Professor Tomović is related to his understanding of the most important duty that a university professor has. "Don't stay at home, go towards the world and find out for yourself where you stand professionally" was not just a moto for him. He actively helped us, his collaborators, to achieve this goal. Once there, his role was finished, we were left on our own, to cherish our memories of this period of growing up with professor Tomović.

CLOSING REMARKS: DEJAN POPOVIĆ