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SCIENCE AND TECHNOLOGY ISSUES THROUGH THE DEVELOPMENT OF ROBOTICS

Abstract: Contemporary robotics is a branch of science studying the intelligent systems whose main characteristic property is movement. Such systems can be divided into industrial robot manipulators, mobile robots, man-machine systems and biologically conceived robots. Special attention is paid to development of robot cells with human operators, robotic education games for children, rehabilitation robotics, and research in humanoid robotics.

Along with robotic developments, the following science and technology issues are discussed: establishment of small, high technology and family enterprises, the needs for informal education in engineering, roboethics, the importance of proper science evaluation and research based innovation. The education of robotics in parallel with internationalization of universities is also presented.

Key words: *industrial robotics, rehabilitation robotics, humanoid robotics, education in robotics*

INTRODUCTION

The word „robot" does not originate from a science or engineering vocabulary. It was first used in the Czech drama R. U. R. (Rossum's Universal Robots) written by Karel Čapek and was first played in Prague in 1921 (the word itself was invented by his brother Josef) [1]. In the drama the „robot" is an artificial human being which is a brilliant worker, deprived of all unnecessary qualities: feelings, creativity and capacity for feeling pain. In the prologue of the drama the following „definition" of robots is given: *Robots are not people (Roboti nejsou lidé). They are mechanically more perfect than we are, they have an astounding intellectual capacity, but they have no soul. The creation of an engineer is technically more refined than the product of nature.* The Slovenian translation of the drama was published in the same year as the Czech original [2].

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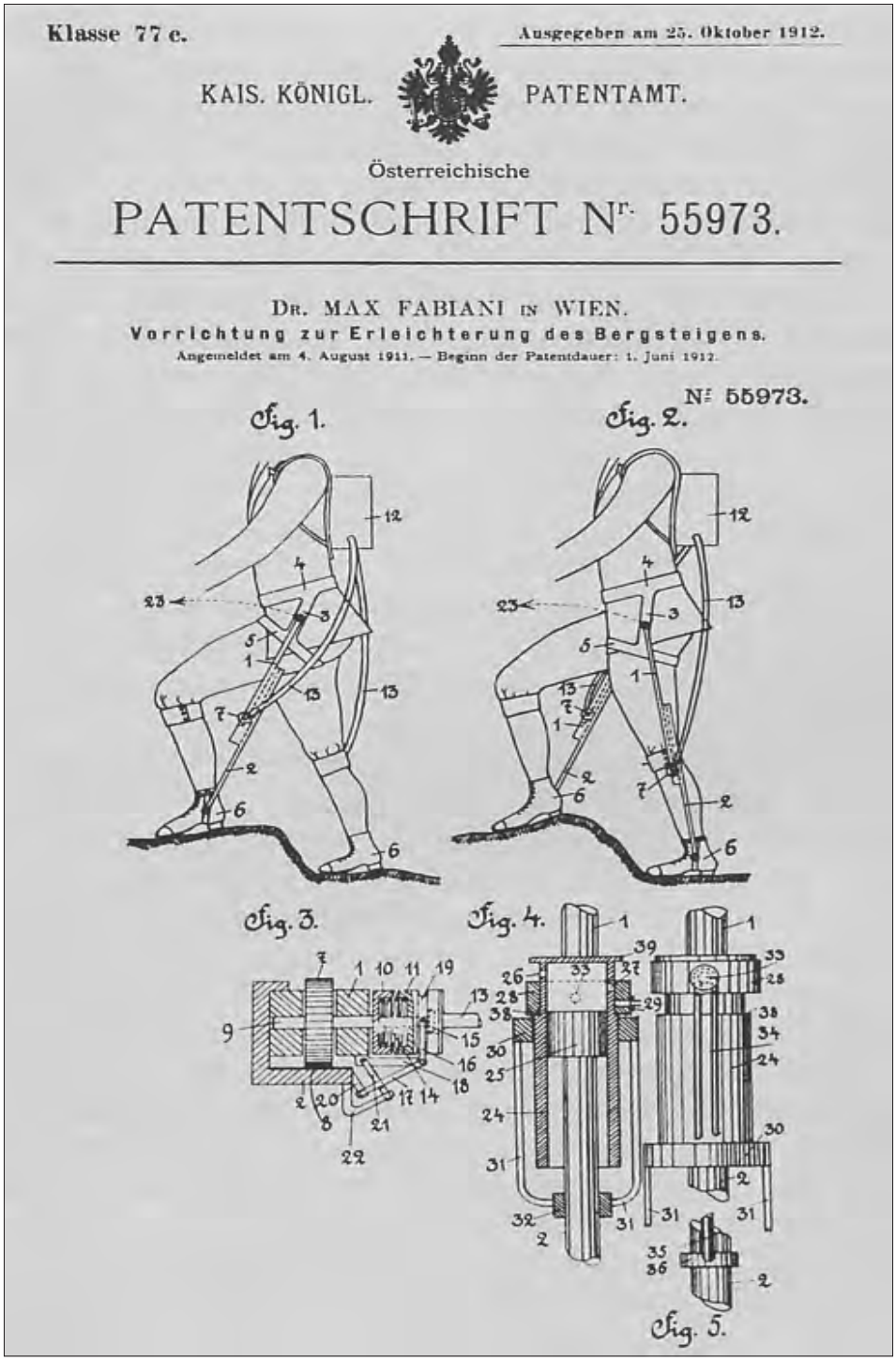
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KAIS. KÖNIGL. PATENTAMT.

Österreichische

PATENTSCHRIFT Nr. 55973.

DR. MAX FABIANI IN WIEN.

Vorrichtung zur Erleichterung des Bergsteigens.

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Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

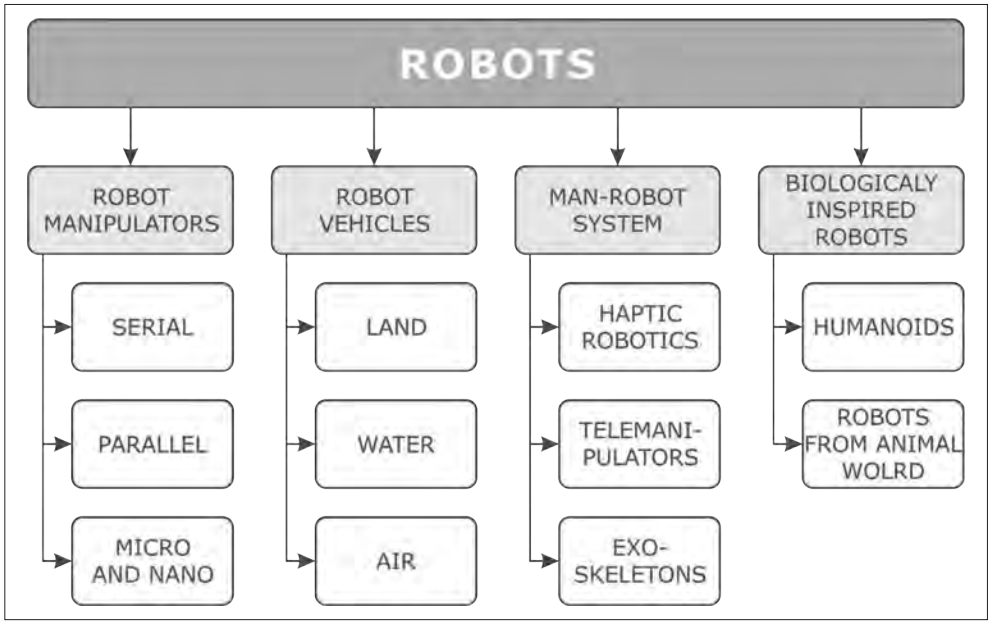
Picture 1. Fabiani's patent application

The patent application for an exoskeleton robot can be considered as an early achievement of Slovenian robotics (Picture 1). The aim of this robot device was to augment the movements of a person executing a task where forces, higher than those provided by human body, are required. Slovenian architect Max Fabiani, author of prominent buildings in Ljubljana, Vienna and Trieste, applied for and received the patent for his „device facilitating climbing to the mountains" already in 1912 before the word „robot" was invented. The proposed system, based on telescopic joints and pneumatic actuators, was, however, never realized. "

An important initiative for development of robotics in Slovenia was the meeting „Movement in Man and Machine" which was in 1982 organized by Slovenian Academy of Sciences and Arts. The participants of the meeting were the most eminent American and Yugoslav roboticists and biomedical engineers. Special attention was given to the analysis and comparison of movements assessed in human extremities, prosthetic devices and robot mechanisms. Of special theoretical importance was the lecture by Professor Richard Paul from the University of Pennsylvania on singularities of robot inverse models. Professor Paul published in 1981 the textbook [3] which significantly influenced teaching of robotics at the University of Ljubljana. Equally memorable was the lecture by Professor Bernard Roth from Stanford University discussing kinematic problems of robot fingers, arms and legs.

Professor Roth, the author of famous book on kinematics [4], has later many times paid a visit to Slovenia. The reason for his visits were the symposia „Advances in Robot Kinematics" initiated by Professor Jadran Lenarčič. The biannual symposia represent a central international event bringing together the researchers specialized in robot kinematics from all over the world. The first symposium was organized in Ljubljana in 1988. The symposium is always accompanied by a book which was initially published by Kluwer and later by Springer publisher. Until now 12 books have been published representing the important source of scientific literature in robot kinematics.

Contemporary robotics is a branch of science studying the intelligent systems whose main characteristic property is movement. Such systems can be divided into four larger groups: industrial robot manipulators, mobile robots, man-robot systems, and biologically inspired robots (Picture 2). The most frequent industrial robot manipulators are serial chains consisting of robot segments connected through the robot joints. More and more frequently used are parallel robots where segments are connected in parallel. In the areas of biotechnology and new materials micro and nanorobots are used manipulating with molecules and particles. Autonomous robot vehicles can be found in land, water and air. Man-robot systems are of special interest in medical environment. Haptic robots and exoskeletons are in combination with virtual environments used in rehabilitation, while telemanipulators are applied in surgery. Biologically inspired robots can be divided into humanoids and robots from the animal world (robotic snakes, fishes, quadrupeds, six- and eight leg walking robots). Humanoid robots are capable of biped locomotion. With further development of robot vision and recognition methods, we can expect that the humanoid robots will soon become close partners in our everyday environment.



Picture 2. Classification of robots

ROBOT MANIPULATORS

First industrial robot manipulators appear in late fifties of the past century when US inventors proposed a „programmable mechanical manipulator" representing the basis for the first industrial robot „Unimate". Slovenian robotics started in late seventies by developing industrial robot manipulators of various structures (anthropomorphic, cylindrical, cartesian) and with different actuation modes. The robots were developed by the researchers of J. Stefan Institute and Universities of Ljubljana and Maribor. In small series they were produced by several Slovenian companies. Soon it became clear that for a small environment such as Slovenia it is economically more efficient to develop robotic manufacturing cells based on the robots produced mostly in other European and Asian countries. A robot cell consists of one or several robots, workstations, storage buffers, transport systems and numerically controlled machines. An example of a robot cell with two laser welding robots is shown in Picture 3. For safety reasons the today's robot cells are surrounded by a wire curtain. The advanced robot cells, however, are based on robot mechanisms that are not any more dangerous for human operator. The novel robot mechanisms are lightweight, made from new materials, and based on control systems, which make the robot compliant when in contact with either environment or worker. These modern robot cells are based on cooperation of a robot with human operator.

The industrial robot manipulators are replacing human operators in hard, monotonous, and dangerous tasks which often take place in unsuitable and unhealthy

Picture 3. Welding robot cell

environment. The industrial robots are reprogrammable and multipurpose. These properties make them interesting for use in various industrial processes such as welding, spray painting, palletizing and in assembly lines. In the world, there are over 1,500.000 industrial robots. Slovenia can be considered as an above average robotized European country with over 1.500 robots.

The development of robot cells is an activity appropriate for small and medium size enterprises. In the last decades, a series of such firms were established in Slovenia. They are introducing various European or Japanese robots into different industrial processes. Such firms are among others Yaskawa Slovenia, ABB Slovenia, Dax Electronic Systems, Fanuc Robotics, Domel, to name a few. Even small family businesses stand out in development of robot cells.

Here it should be also mentioned that in Slovenia the research and development departments in industry are in general half as strong as in more advanced European countries, e. g. neighboring Austria, and by four times weaker than e. g. in Finland. This deficit is to some extent overcome by the cooperation with the academic sphere and even more through the easily adaptable small enterprises. Nevertheless, for future prosperity our economy needs more engineers in their development departments. Also the reputation of Slovenian engineer must be increased by incorporating engineers in all levels of decision making in economy and environmental, societal and political administration.

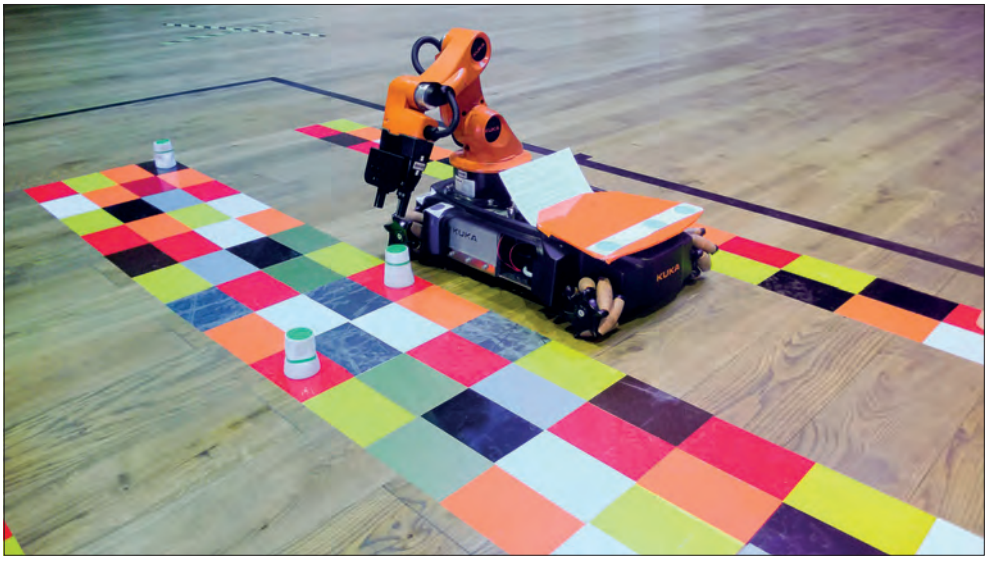
ROBOT VEHICLES

Robot vehicles can be divided into three groups: mobile, underwater and flying robots. The mobile robotic systems are predominantly autonomous vehicles with wheels. These can be robotic vacuum cleaners, autonomous lawn mowers, intelligent guides through department stores or museums, attendants in clinical centers, space rovers, or autonomous cars. The underwater robots usually have the shape of smaller autonomous submarines. Often they are equipped with a robotic arm. They are applied in research of oceans, sea floor, ship wrecks or as attendants on oil platforms. Flying robots are smaller autonomous aerial vehicles usually applied for military reconnaissance missions.

It is interesting to note that all three types of robot vehicles are extensively used also for educational purposes. Students of University of Ljubljana are well known for their successful games of robot football. Here, the players are small cubic mobile robots with two active wheels. The microprocessor inside the robot is wirelessly connected to a computer. A camera above the playground recognizes the positions of the robots and the ball. The most important part of the robotic football is the strategy of the game which is preprogrammed and runs on the computer. The students of University of Maribor are known for their international successes in robotic rescue game. Here, we are dealing with simulation of circumstances that occur in a house demolished by an earthquake. The scene is represented by two floor labyrinth with several rooms. A tracked mobile robot equipped with a gripper is riding over various obstacles, while transporting the „victims" of the accident.

The professors of technical faculties and art academy at the University of Ljubljana have brought together their students at the practical work. This was an exceptional project opening the paradigm of interdisciplinary study, in this case combining media arts and science. Through the use of computer vision, virtual environments, kinesthetic assessments, and various robots they have begun to open an intermediate space for dialogue to ask questions about the essence of the scientific in art and artistic in science. The projects were transferred from laboratories to galleries and other public venues. Picture 4 shows a small mobile robot positioning by the use of the robot arm the objects on various places on the floor. In the so called „imitation game" the robot is copying the movements of a visitor of the gallery performing the same task. After a while it is not clear whether robot is copying human or human is copying robot.

The students of the secondary school Gymnasium Vič in Ljubljana developed a research submarine named Calypso. During the project work outside their regulary school hours they gained considerable knowledge on how to design the hydrodynamic shell of the submarine, how to select the appropriate actuators and microprocessors and preprogram the movements of the underwater robotic vehicle. The submarine Calypso was already deployed into the depths of the Slovenian sea. The quadcopters are relatively inexpensive flying robots and are very appropriate for various educative purposes. The quadcopters are equipped with gyroscopes, accelerometers, cameras and wirelessly connected to a stationary computer. In an in-



Picture 4. Mobile robot with a robotic arm involved in an artistic project

teresting student project the quadcopter was used to collect the seeds from the top of the high pines.

Informal education in engineering is of utmost importance. In grammar and secondary schools the teaching of technical subjects is underestimated in Slovenia. Because of financial requirements the technical contents are often simplified in the grammar schools, while students in general secondary schools (so called gymnasia) do not even hear the words such as engineering and technology. As a result the number of graduates from technical faculties is below the European average and Slovenia is lacking the sufficient population of engineers necessary to increase the competitiveness of its industry.

MAN-ROBOT SYSTEMS

Rehabilitation robots play an important role in the group of man-robot systems. They can be either haptic robots or exoskeletons. Haptic robots provide the user with the feeling of touch, limited motion, compliance, friction, and texture in virtual environment. Small haptic robots are usually used for assessment and evaluation of movements of upper extremities in paralyzed persons. Stronger haptic systems can hold the wrist of a paralyzed person and guide the arm end-point along the desired path which is shown to the subject in virtual environment presented on the computer screen. The haptic robot exerts two types of the forces to the subject's wrist. When the patient is unable to perform a movement along the path shown to him in the virtual environment, the robot pushes the wrist along the required trajectory and helps the patient to accomplish the task. The robot is helping only to the extent necessary for the patient to reach the goal point. When pa-

Picture 5. Robot in rehabilitation of upper extremity

tient's paralyzed extremity travels away from the planned curve, the robot pushes the wrist to the vicinity of the required trajectory. Similar therapeutic robotic exercise can be performed also by the use of exoskeletons. Exoskeletons are active mechanisms, which are attached to human upper or lower extremities. The upper extremity exoskeleton ARMIN with seven degrees of freedom (four in shoulder, one in elbow and two in wrist) developed by ETH Zürich in collaboration with University of Ljubljana is presented in Picture 5 [5].

Rehabilitation robotics is a relatively new research area and is most appropriate to create new rehabilitative devices or new therapeutic procedures. Unfortunately, the Slovenian research evaluation system is in general not very much in favor of innovations. The Slovenian research system was in the year 2012 criticized by the OECD by the following statement [6]: *As the evaluation of the academic research work is almost exclusively based on bibliometric methods, this is not an incentive for the researchers from the universities and institutes to collaborate with industry in an innovation process*. With regard to the number of scientific publications, Slovenia is on excellent 7th place in Europe. On the other side Slovenia is below European average in patenting.

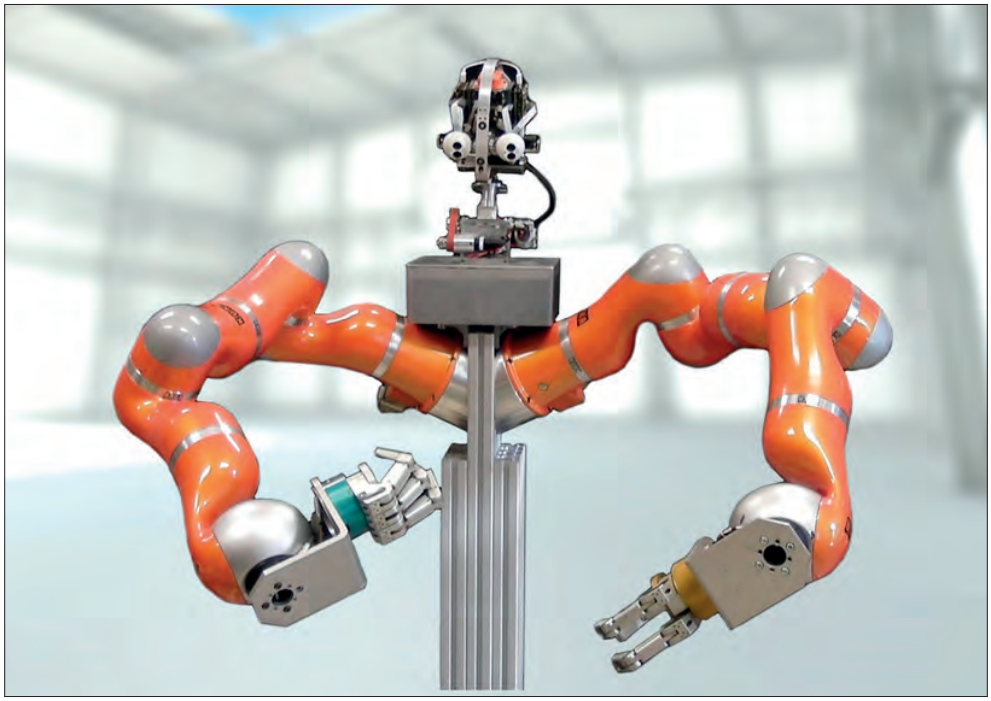
As similar situation can be found also in several other European countries, the word „*innovation*" will have to play an ever more important role. Here, as scientists we are predominantly interested into the „*research-based innovation*". It can be an accomplishment of either applied or basic research. It is important that it meets the expectations of society and is internationally competitive and economically prom-

ising in order to persuade political and economic leaders. The research-based innovation is often ill defined. Therefore, the European organization Science Europe proposed the following definition [7]: *Research-based innovation is an attempt to change something already established by introducing new services, products or processes to companies, governments or civil society actors, relying on knowledge that was not previously used in this area and that has been acquired through conducting research*. Research-based innovation is in Slovenia not adequately appreciated in the research environment itself and does not meet the expectations of society and of political and economic leaders. The situation can be improved by changing the evaluation practices of the research results. The research evaluation should not be based only on the knowledge published in peer-reviewed journals, but should take into account also knowledge produced in non-traditional forms, such as patents, prototypes, data, software, and other relevant knowledge.

BIOLOGICALLY INSPIRED ROBOTS

Humanoid robots are by far the most advanced robot systems in the group of the biologically inspired robots. Humanoid robots are adapted to live and work in human environment. The most noticeable property of humanoid robots is their ability of bipedal walking. They walk either with statically stable or dynamically stable gait, they can balance while standing on a single leg, they move in accordance with human co-worker, they can even run. Today's problems of humanoid robotics are related to artificial vision, perception and analysis of environment, natural language processing, human interaction, cognitive systems, machine learning and behaviors. In Slovenia the researchers of J. Stefan Institute are developing robots who learn about their own behavior from human demonstration (Picture 6). The robots are learning also from the experience, while replicating natural processes, such as trial-and-error and learning by doing, similar to that of a small child [8]. It this way the humanoid robot gains a certain degree of autonomy which further means that humanoid robots can behave in some situations in a way that is unpredictable to their human designers.

Humanoid robots are coming into our homes and are becoming our partners. They will soon be companions to the elderly and children, assistants to nurses, physicians, firemen, and workers. There is a rising need to embodying ethics into a robot. This new emerging ethics is called roboethics. *Roboethics is an applied ethics whose objective is to develop scientific/cultural/technical tools that can be shared by different social groups and beliefs. These tools aim to promote and encourage the development of robotics for the advancement of human society and individuals, and to help preventing its misuse against humankind* [9]. The outstanding novelist Isaac Asimov already in 1942 formulated his famous three laws of robotics. Later on, in 1983, he added the fourth law, known as the zeroth law: *No robot may harm humanity, or through inaction, allow humanity to come in harm*. New generation of humanoid robots will be partners that coexist with human beings, who assist human beings both physically and psychologically and will contribute to the realization of a safe and peaceful society. They will be potentially more ethical than humans.



Picture 6 Experimental humanoid robot

CONCLUSIONS

Let us devote the concluding remarks to the education issues. The history of education in robotics has at University of Ljubljana over 30-years long history. The first Slovenian robotics textbook was published in 1985, only four years after the first US textbook [3]. Today the Slovenian professors can proudly present themselves by a series of textbooks written both in Slovenian and English language. Their English textbooks were published by respectable international publisher Springer [10–14]. The textbook *Robotics* (Picture 7) is characterized by simple and original treatment of rather complex areas of kinematics, dynamics and control of the robot systems. American magazine *Choice* placed *Robotics* among the best academic books in the year 2010. The robotic textbooks can be reached from the web.

Internationalization of the universities is an important issue in Slovenia which has been an independent state for only 25 years. Slovenians developed their identity based on their language. The language is the value which connects Slovenians for one and a half millennium. It is therefore not difficult to understand that the teaching language in four Slovenian universities is more or less exclusively the Slovenian language. Single English courses are with difficulty entering the university teaching programs. On the other side, Slovenian universities would like to attract more international students and professors which is not only a profit but also a honor for an university. An important step in the process of internationalization of the uni-

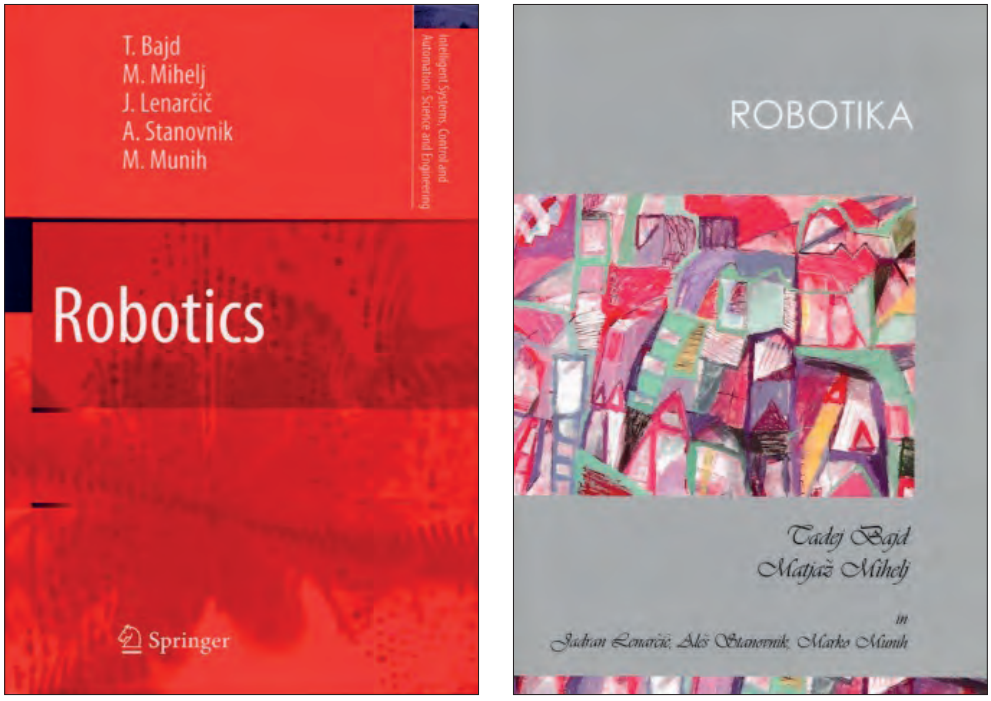


Fig. 7. Slovenian and English edition of the textbook *Robotics*

versities is in preparation of the teaching material, i. e. textbooks, lecture notes, video lectures and transparencies, both in Slovenian and English language. This is not such a difficult task with ever more extensive use of e-learning. This approach can calm those who are afraid that the Slovenian language can soon become the so called „3 F language" only used by family, friends and folk songs.

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