First Experience with a New Biomedical Engineering Program in Slovenia Established Following the TEMPUS IV CRH-BME Joint Project Guidelines

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Abstract— **A new study program of biomedical engineering was recently established at Faculty of Electrical Engineering, University of Ljubljana, Slovenia. It is based on the long-lasting tradition of education in the field of BME at the host institution and is built on the BME areas in which the research groups of the Faculty of Electrical Engineering have been traditionally successful. The program was prepared in accordance with the recommendations of the TEMPUS IV CRH-BME Project consortium.**

I. Introduction

Biomedical engineering (BME) is a relatively young engineering discipline characterized by rapid development and wide diversification and broadening of its areas of application. In Europe the affirmation of BME as a discipline with a clear distinction from the other traditional engineering disciplines is sometimes still problematic, at least partially due to differences between countries. The number of BME programs offered by higher education institution across Europe, however, is growing rapidly. According to a survey performed in 2009 there were more than 300 different BME programs available across Europe at that time and this number represented a more than three-fold increase within a period of only 10 years [1]. There are large differences between the BME or BME-like study programs at universities throughout Europe. In most cases these programs originate from one of the traditional engineering disciplines (electrical, mechanical, chemical engineering). This is also the case with our new BME program at University of Ljubljana, Faculty of Electrical Engineering, which was started in the academic year 2012/13. In this paper we present our program and our initial experiences.

II. Biomedical engineering at University of Ljubljana

University of Ljubljana is by far the largest and most influential of the three Slovenian universities (60,000 students and 4,000 teachers), offering a comprehensive selection of various study programs by its 23 Faculties (member schools) and 3 Academies. Even though the activities in the field of BME have existed at various higher education institution for many years (most notably at Faculty of Electrical Engineering), a formal study program of BME had not been offered until recently.

A. History of BME education at Faculty of Electrical Engineering

Biomedical engineering has been present at the Faculty of Electrical Engineering of University of Ljubljana since the 1960s when the Laboratory of Medical Electronics and Biocybernetics was established. This can be considered as the beginning of higher-education activities in the field of BME in Slovenia. The founder, professor Lojze Vodovnik, was at the time one of the leading scientists in the field of functional electrical stimulation, which was for more than a decade the main area of activities and which brought the international recognition and reputation in this field to the Ljubljana team. It was about 10 years later, in 1977, when a specialization track called Cybernetics in Medicine was introduced for the first time into the study program. It was one of four specialization tracks available within the Control Engineering module offered to students within the Electrical Engineering program. Cybernetics in Medicine comprised a selection of biomedically oriented engineering courses, thus making the program comparable to some biomedical engineering programs offered at other universities. Over the years, the activities in the field of BME spread to many other laboratories and research groups at the Faculty of Electrical Engineering. In 2006 the Department of Biomedical Engineering was founded. At that time all study programs at University of Ljubljana were undergoing a renovation in order to make them compatible with the requirements of the Bologna process and the concept of European Higher Education Area, which is supposed to ensure more comparable, compatible and coherent systems of higher education in Europe and to promote easier mobility of students and staff among European universities [2]. The Department of Biomedical Engineering was thus charged with the responsibility to prepare and organize a new study module program for biomedical engineering, which replaced the Cybernetics in Medicine specialization track and became the first official BME program in Slovenia [3].

B. The new BME study program

Since the academic year 2012/13, the program of Biomedical engineering is offered as one of seven modules of the new 2nd cycle (Master's level) study program at the Faculty of Electrical Engineering. The other six study modules are: Automation (Control Engineering), Power engineering, Electronics, Mechatronics, Robotics, and Telecommunications. The modules have independent

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curricula with a maximum possible overlap of 20%, which is realized in terms of elective courses.

The BME curriculum is outlined in the following subsection. The courses are run by teachers of the Department of Biomedical Engineering and some other departments at our school. The whole program (an equivalent of 120 ECTS credits) takes four semesters (30 ECTS each) to complete. Three semesters are dedicated to courses. Each course comprises lectures and practical work with a total of 75 contact hours and 6 ECTS. The last semester is reserved for the design- and/or research-oriented work leading to the master's thesis.

C. The curriculum

Biological Systems. This course introduces the biological systems to engineers. It provides the fundamentals of biochemistry, self-organization on molecular level, the structure and function, of a biological cell, the physiological systems and the regulatory mechanisms for maintenance of homeostasis in the human body, molecular genetics and thermodynamics of biological systems.

Biomedical informatics. The course is focused on storage, access, protection, transfer, standardization and optimal usage of biomedical data and information, as well as management and integration of biomedical data and information for the purpose of increasing the quality and efficiency of the decision making process in various fields of healthcare, engineering, social and economy domains.

Measurements and sensors in biomedicine. This course provides an overview of physical and physiological quantities relevant to clinical and research medical environment and of physical principles of measurement methods and sensors. The students gain practical experience by measuring differnt signals from the body and by using measurement methods in biological laboratory.

Biomedical electronics. Students learn about electronic circuits and devices encountered and used in clinical and research medical environment. Practical experience is gained by using some of the instruments and by building and testing biopotential amplifiers and other electronic circuits. The course also provides an introduction to standards and protection against electrical hazards in medical environment.

Numerical modeling of physical phenomena in engineering and biomedicine providing the students with knowledge and experience in using mathematical modeling and numerical methods for solving problems drawn from different areas of engineering, medicine and biology. A particular emphasis is given to methods for solving systems of partial differential equations and to optimization.

Neurocybernetics This course focuses on excitable cells and tissues. The aims of the course include the understanding of the functioning of these systems, sensing of external stimuli, internal processing and integration of the acquired information from the environment, generation of the reaction to these stimuli, and the restoration of lost physiological functions by technological means.

Biomedical signal processing. The origin, nature and characteristics of commonly encountered biomedical data and signals are presented. Students get insight into theoretical background of various methods for processing of stochastic signals. Practical experience in gained by applying signal processing methods for extraction of clinically relevant information from various biomedical signals.

Biomedical imaging techniques. This course serves as an introduction to the devices and technologies for the acquisition of biomedical images (microscopy, x-ray imaging, computed tomography, magnetic resonance imaging and ultrasound imaging), and to methods for restoration, reconstruction, calibration and integration of biomedical images and image quality improvement.

Robots in contact with humans. The students learn about the robots that interact with humans or living matter in general. The important principles of robotics are covered and used as the basis for multimodal human-robot interaction. The concepts of audiovisual virtual environments and haptic interaction are presented. The knowledge is applied to systems in rehabilitation, teleoperation and service robotics.

Biomechanics. In this course the students are familiarized with fundamental laws of mechanics and with the application of these laws to understanding of and analyzing the living systems. The foundations of biomechanics that are developed in this course include the mechanics of materials and structures, fluid dynamics and locomotion, particularly those pertaining to sports and rehabilitation.

Medical image analysis. Computational tools for analysis of images of a multitude of different medical imaging modalities and are in the focus of this course. Principles and methods of automated medical image analysis are explained. Topics in image segmentation and image registration and shape modeling are explored in the context of different applications such as image-guided interventions.

Data analysis and mining in biomedicine. This course concerns itself with extraction of knowledge from sets of biomedical data. It is an introduction to the field of intelligent systems, data mining techniques, basic model identification, dynamical model identification, and model validation. Concepts such as expert systems, fuzzy logic, pattern recognition and neural networks are presented.

Bioelectromagnetics. This course introduces the scientific foundations of the mechanisms of interaction between ionizing and non-ionizing electromagnetic fields and biological systems. Characterization of the sources of these fields, their measurements and dosimetry, the most important experimental and epidemiological studies, as well as the scientifically based limit values are presented.

Communication in research and development. This course is aimed at developing communication skills and competences for presenting research and development achievements to peers and experts as well as to general public using various presentation tools. Efficient methods of communication within the organization or a team for maximizing the productivity is also emphasized.

Seminar in BME. The seminar prepares the students for independent and in-depth research- or design-oriented work on the thesis in the last semester. Students are presented with a comprehensive real-life problem in order to gain experience in analyzing the problem, searching for viable solutions and selecting and applying the most appropriate methods and tools in order to solve the problem. Presentation of the results in the form of written reports and oral presentations and critical evaluation and reflection on the work are important components.

D. Commentary

In all courses roughly one half of the contact hours are dedicated to practical work, which is realized in different forms, some of it as traditional laboratory work with weekly assignments. But in most courses one part of lab work is replaced by projects in which students are challenged with small practical problems. Solving these problems requires combining and integrating the knowledge obtained in different courses with additional and independent study. An example of this approach are the projects done in the framework of the courses, *Measurements and sensors in biomedicine* and *Biomedical electronics*, which run in parallel and cover biomedical instrumentation. Students are offered a selection of various sensors (e.g. pressure, flow, temperature, light, pH, etc.) and a selection of specific problems to be solved using these or some other sensing devices. The activities that students must perform in order to complete the project successfully include:

- searching the literature to investigate the problem and find viable (realizable) solutions;
- choosing an appropriate sensor (not necessarily one of those available initially) and designing and building the electronic circuitry to drive and read the sensor (using Arduino platform);
- testing the sensor performance and performing the measurements to arrive at the required data and analyzing the data;
- writing a report with evaluation of the sensor performance and the results (even if they are "negative") with suggestions for improvements and presenting the project in front of their colleagues.

The education process is also supplemented by visits to local medical institutions (the Institute of Oncology, the University Medical Center Ljubljana, and the Institute of Rehabilitation of Slovenia) and selected companies working in the field of BME and by lectures given by invited experts from the collaborating institutions from different countries.

III. Recommendations of TEMPUS IV CRH-BME Joint Project

The TEMPUS IV Joint Project under the title "Curricula Reformation and Harmonization in the Field of Biomedical Engineering" (CRH-BME, 2009-2012) was a European project with participants from 23 universities from 20 EU and partner countries. The activities within this project built on the results of two previous European initiatives (TEMPERE [4] and BIOMEDEA [5]), which were all aimed at affirmation of BME as an independent engineering discipline, at harmonization of the study of BME and at development of the criteria for education, accreditation and certification in this field. One of the aims of the CRH-BME project was to develop a set of recommendation for establishment of new and modernization of the existing 1st and 2nd cycle BME programs. The idea of these recommendations was to promote the harmonization on one side and to preserve and take advantage of complementarities of the different BME programs on the other side. Detailed description of the recommendations can be found in [6,7] and the details about the compliance of our BME program with these recommendations in [3]. Only an outline of the key points is presented here.

A. Types of BME programs

The CRH-BME consortium identified a need for five distinct types of BME study programs reflecting different backgrounds of the students: a) The stand-alone 1st cycle BME program; b) The stand-alone 2nd cycle BME program for graduates of 1st cycle non-BME engineering or physical sciences programs; c) The stand-alone 2nd cycle BME program for graduates of 1st cycle BME engineering programs; d) The stand-alone 2nd cycle BME program for graduates of biological or medical programs; e) The integrated 1st and 2nd cycle BME program. Our BME program clearly belongs to the type b) in the above list This is also the most frequently encountered type of BME programs throughout Europe.

B. Content categories and ECTS credits

For each type of the BME programs the division of ECTS credits among 10 content categories was recommended to accommodate different backgrounds of the enrolled students. These content categories are: 1) Basic engineering and physical sciences; 2) Engineering and physical sciences focused on BME applications; 3) Basic biological and biomedical sciences; 4) Biological and biomedical sciences focused on BME applications; 5) General introduction to BME and BME specialization; 6) Generic skills; 7) Ethics (general, medical, research); 8) Management & quality assurance; 9) Visits to/from companies, lectures and seminars; 10) BME research or design project for thesis. The distribution of credits of our BME program among the 10 content categories is largely in agreement with these recommendations.

C. Core BME curriculum

The CRH-BME consortium defined the generic core BME curriculum in terms of seven core topics rather than courses. A core topic was defined as a category broader than a course which can be covered by more than one course, depending on the expertise and objectives of the BME program. It was recommended that any BME program should cover in width and detail at least four of these core topics, which are: i) Biomaterials; ii) Biomechanics; iii) Biomedical instrumentation and sensors; iv) Biomedical

signal processing; v) Health technology design, assessment and management; vi) Information and communication technologies in medicine and health care; and vii) medical imaging and image processing. The curriculum of our BME program follows the recommendations by including five of these core topics (numbered ii, iii, iv, vi, and vii).

IV. Experience after the first two years and future prospects

The new BME program has been running for only two years, therefore the first graduates are expected in the fall of 2014 and it is to early for any conclusive evaluation of our success. The inscription in the first year of study for the first two generations was smaller than expected (7 and 9 students for 2012/13 and 2013/14 generation respectively). These numbers are smaller than those for students of the Cybernetics in Medicine specialization track in the old study program, in which the number of enrolled students varied between 5 and 18 with the average of 12. Therefore we are not satisfied with the current inscription. The current capacities of the Department of Biomedical Engineering are between 16 and 20 students. We believe that one of the reasons for not reaching the desired inscription numbers is the fact that the students of the 1st cycle of Electrical Engineering at our school (which is currently the primary source of students for all 2nd cycle study modules) have no opportunity for the first-hand introductory exposure to the field of BME during the first three years of study. All other 2nd cycle study modules except the BME have an advantage of being represented within the 1st cycle program either by the corresponding 1st cycle study modules or at least by elective courses. On the other hand, the expression of interest for our BME program from students of 1st cycle programs from other Faculties of University of Ljubljana is substantial and is increasing (some of them are our current students), most notably from Faculties of Physics, Pharmacy, Chemistry, Biotechnology, Mechanical Engineering, and Computer Sciences. Our goal for the future is to attract more students from these schools as well.

In the present program a small part of lectures and practical work for two courses is organized in collaboration with Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia. There are three reasons for this: 1) our students get practical experience with the equipment for standardized electrical safety testing of various types of medical devices, which we currently do not have; 2) our students are given lectures on topics in which our colleagues in Zagreb are specialists; 3) students appreciate the change and the experience of education process in a different country. We intend to keep and intensify this cooperation based on complementary expertise offered by programs in Ljubljana and Zagreb. During the academic year 2013/14 a group of students from University of Zagreb had a part of their regular education process organized at our school because of our expertise and availability of facilities in the field of cellular engineering.

Our plans for the future are to prepare and submit for accreditation of a completely new 1st cycle BME program in collaboration with either Faculty of Health Sciences or Medical Faculty and possibly with some other engineering faculty, which can lead to diversification of the existing 2nd cycle BME program. There are also plans for establishing joint degree programs in the field of BME with universities in the neighboring regions from Slovenia, Croatia, Austria and Italy, which are located relatively close together and have complementary BME programs. We are convinced that this kind of cooperation is the best opportunity for affirmation of BME studies in this region and for improved international recognition of the local BME study programs.

The Slovenian BME industry, although still relatively scarce, is growing. New highly specialized small companies are emerging and several larger and well-established high-technology manufacturers are now dedicating more and more of their efforts to development, manufacturing and global marketing of BME products. A so-called Center of Competency – Biomedical Engineering was initiated in 2011 on national level as a response of Slovenian industry (small and large high-tech enterprises) to the challenges of the global markets and the growing need of the local industry for BME engineers. Within this consortium comprising all major players in the BME field in Slovenia (industrial partners, academic institutions, research institutes and medical centers) the work is dedicated towards development of new products and services for the industrial partners.

In the last years there was a steady decline in the number of students enrolled in the study of traditional electrical engineering in Slovenia. Formation of new attractive and up-to-date programs of high quality and responsive to the urgent needs of the modern society is the right way to increase the interest of students in engineering in general. The growing concern of the modern society for the issues concerning the environment, energy and health must be reflected in the changes in the educational system. We believe that the field of BME is addressing these challenges.

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