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A new biomedical engineering study program adopted at the Faculty of Electrical Engineering of University of Ljubljana

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Abstract. In the last years, the field of biomedical engineering (BME) has been one of the fastest growing and developing engineering fields, world-wide. It also has an important and long-lasting tradition at the Faculty of Electrical Engineering of University of Ljubljana in both research and education. During the recent process of renewal of the current study programs to comply with the Bologna declaration the BME field has been adopted as a 2nd cycle study program. It will be offered to the students for the first time in the study year 2012/13. Preparations for the new BME study program have been running in parallel with the activities of an international project on modernization and harmonization of BME programs in Europe. One of the main objectives of this project (Tempus IV Joint Project: Curriculum Reformation and Harmonisation in the field of Biomedical Engineering – CRH-BME) is to propose the guidelines for updating the existing and formation of new BME study programs. The new BME study program adopted at the Faculty of Electrical Engineering complies with the CRH-BME recommendations.

Keywords: biomedical engineering, study program, higher education, harmonisation

1 INTRODUCTION

Biomedical engineering (BME) is a bridge between different engineering disciplines on one side and medicine and biology on the other side. BME uses the engineering approach to help solve problems of medical nature and of health sector in general. BME is a relatively young discipline and as such it is in the process of affirmation as an independent professional and scientific field. The main characteristics of BME are its interdisciplinary character and a high rate of development and diversification into many highly specialized sub-disciplines. The latter is especially evident in the last time and can be observed in the rapid development of new diagnostic and therapeutic procedures and in the increasing role of information and communications technologies in management of patients. The need for BME experts in medicine and health sector in general is increasing everywhere in the developed world. In 2006 there were more than 400,000 people employed in the medical device industry in the EU and at the same time there were about 20 million people working in the health care and social services sectors [1]. As a consequence of the increasing demand for BME engineers, the number of universities offering BME studies has also been increasing. A recent European survey has shown that there are currently more than 300 different BME programs available at European universities. This number represents more than a three-fold increase over a period of only ten years [2].

At most universities, the BME programs originated from one of the traditional engineering disciplines, such as electrical, mechanical, or chemical engineering. Because of this, many BME programs focus on BME topics which are closer to the parent engineering discipline. For example, BME programs derived from the interaction between electrical engineering and medicine tend to specialize in biomedical instrumentation, medical electronics, medical imaging and biomedical signal and image processing. BME programs originating from mechanical engineering often specialize in biomechanics, biotransport and instrumentation. Chemical engineering-based BME programs are often biased towards biomaterials, biochemistry and cell and tissue engineering. But nevertheless, all BME programs share many common topics and characteristics.

The profile of the BME engineer therefore encompasses professionals with very heterogeneous areas of specialization sharing common characteristics which define them as biomedical engineers and make them unique among the engineers. Every BME engineer must possess a sound and relatively broad knowledge of fundamental engineering and physical science principles. However, unlike other engineers, she/he must be able to apply this knowledge to solve problems of biomedical origin, which requires the knowledge about the principles of living organisms. Because of this interdisciplinary character it is not surprising that the

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majority of the existing BME programs are organised as the 2nd or 3rd cycle programs (M.Sc. or Ph.D. level), and most of the enrolled students are the 1st cycle graduates of various traditional engineering programs. However, the number of the 1st cycle BME programs is also increasing. In the USA, where the BME discipline has strong and long tradition, some universities consider graduation from the 1st cycle BME program as an ideal starting point for the study of medicine.

BME has a long-lasting tradition at the Faculty of Electrical Engineering of University of Ljubljana. The foundation of its Laboratory of Medical Electronics and Biocybernetics in the 1960s represents the beginning of research and higher-education activities in BME in Slovenia [3]. Initially, the main area of these activities was the functional electrical stimulation. The Ljubljana group under the leadership of its founder professor Lojze Vodovnik achieved international recognition and reputation in this field. In 1977, the students were for the first time offered a study module *Cybernetics in Medicine* as a specialization track within the Automation study program. The module combined a number of biomedically oriented courses, thus making the study program comparable with the BME programs running at some other universities. Over the years to follow, the number of laboratories involved with the area of BME at the Faculty of Electrical Engineering has increased.

The study module Cybernetics in Medicine is currently still offered at the Faculty of Electrical Engineering in the last two years of the five-year undergraduate program of electrical engineering. However, in the study year 2012/2013 it will be replaced by an extended stand-alone program of *Biomedical Engineering* as part of the new 2nd cycle program as the first official BME program in Slovenia [4].

2 RECOMMENDATIONS FOR BIOMEDICAL ENGINEERING PROGRAMS IN EUROPE

Biomedical engineering is still a relatively young discipline characterised by rapid development and broadening of its application areas. In the recent past there were several attempts (in the USA and the EU) to provide a definition of the BME study programs in a way that will make a clear distinction between BME and other traditional engineering disciplines [5,6]. This process has been more problematic in Europe, mostly due to differences between many countries, while in the USA the BME field is more firmly established. In Europe, the BME field (and clinical engineering, i.e. a BME sub-discipline) has so far received the widest recognition in the UK and Italy. A lot of effort has already been dedicated in Europe to harmonisation of the study of biomedical engineering and to development of criteria concerning education, accreditation and certification in this field. One such attempt was a large trans-European project within the SOCRATES program called TEMPERE (Thematic network or Training and Education in Medical Physics and Biomedical Engineering), which was running between 1996 and 2000 [7]. In 2004 a new all-European initiative was started under the acronym BIOMEDEA (Biomedical and Clinical Engineering Education, Accreditation, Training and Certification), founded in collaboration with the IFMBE (the main world-wide organisation of biomedical engineers) and sponsored by the WHO [5].

The latest initiative of this kind, which builds on the results and experience of the TEMPERE project, is the TEMPUS IV Joint Project *CRH-BME - Curricula Reformation and Harmonisation in the Field of Biomedical Engineering* [8]. CRH-BME has been running since 2009 and is approaching its completion in 2012. Representatives from 25 universities from 20 EU and partner countries collaborate in this project. One of the main goals of CRH-BME is to propose a set of recommendations for establishment of new and modernization of the existing BME study programs. The purpose is to promote harmonization of BME programs (to make them more comparable) but at the same time to take advantage of their complementarities (exploit specific differences between them). This would also facilitate mobility of students and teaching staff between universities, which would contribute to formation of the European Higher Education Area (EHEA) [9].

2.1 Types of BME programs

Based on the analysis of the current situation and on projection of future needs, the CRH-BME project group identified a need for five distinct types of programs presented in Table 1. The ECTS credits were divided between ten content categories for each type of the BME programs. The recommended types of programs are [10]:

A) <u>*Stand-alone 1st cycle BME program*</u>. It is meant to satisfy the growing needs of industry and health sector for immediately employable BME engineers. It can serve as an entry point for the 2nd cycle BME or other engineering programs.

B) <u>*Stand-alone 2nd cycle BME program (entry from the 1st cycle non-BME engineering or physical sciences program).*</u> This is the most common BME program type. Students are expected to possess a sound background in engineering, physics and mathematics, but little or no background in the university-level medicine or biology.

C) <u>*Stand-alone 2nd cycle BME program (entry from the 1st cycle BME program)*</u>. The starting point is different from that of type B, which reflects in different distribution of credits to the basic engineering and biomedical categories shown in Table 1. Graduates of the type B and C programs are expected to possess very similar BME knowledge and skills.

D) <u>*Stand-alone 2nd cycle BME program (entry from the 1st cycle biological program or medicine)*</u>. The need for this type of programs is increasing due to the fast technological advances and specifics of some areas of clinical medicine and laboratories, where a specific BME expertise is an advantage (orthopaedic and plastic surgery, rehabilitation, etc.). The engineering knowledge and skills of the type D graduates are of course below those of the type B, C or E.

E) <u>*Integrated 1st and 2nd cycle BME.*</u> This is an alternative to the type B and C programs. It may be more flexible in organisation of the curriculum and may provide a bit more width and depth in the BME-specific topics due to no overlap in contents, which is inevitable in case of the stand-alone 1st and 2nd cycle programs.

Table 1: Recommendation for the generic BME programs for the 1st and 2nd cycle of the Bologna programs. The numbers are ECTS credits.

	Program types*				
Content category	A	B	C	D	E
1.) Basic engineering and physical sciences	70	5	15	20	100
2. Engineering and physical sciences focused on BME applications	20	10	10	10	40
3. Basic biological and biomedical sciences	15	20	5	5	25
4. Biological and biomedical sciences focused on BME applications	20	10	10	10	30
5. General introduction to BME and BME specialization	30	15	20	15	60
6. Generic skills 7. Ethics (general, medical, research) 8. Management & quality assurance 9. Visits to/from companies, lectures and seminars	10	5	5	5	15
10. BME research or design project for thesis	15	25	25	25	30
Minimum total ECTS credits *	180	90	90	90	300

*See the text for explanation.

Because of the different expertises and facilities of the host institutions there will always be some differences between BME programs at different universities. To accommodate these differences, it was recommended that variations of up to 25% in individual categories of Table 1 (or up to 10 credits) should be acceptable. Only the minimum total number of credits is specified in Table 1 for each type of the program. To comply with the Bologna requirement of 300 ECTS credits for the 1st and the 2nd cycle together, either the 1st or the 2nd cycle must provide additional 30 credits. In most cases this requirement is fulfilled by the 2nd cycle. At majority of universities the 2nd cycle studies take two years to complete and provide 120 credits.

The differences between the program types in the number of credits (Table 1) reflect different backgrounds of the enrolled students but also different objectives of the programs. Credits allocated for the engineering and the biomedical components are subdivided into "basic" (1 and 3) and "applied" categories (2 and 4) in Table 1. Courses belonging to the applied categories are built on foundations provided by the basic courses by using examples from the BME practice. Category 5 contains courses that either cover the introductory BME materials or are used for specialization purposes within narrow BME sub-disciplines. Non-engineering "transferable" skills and knowledge needed for successful work in the interdisciplinary environment are covered by categories 6-9. The awareness of ethical issues (especially medical) is a requirement asked only of BME engineers. A research or design project in the BME field is also a compulsory component of every BME program (category 10) leading to a graduation thesis [10].

2.2 *Generic BME curriculum*

In the past there have been several attempts to formulate a set of contents or courses that could in themselves be used as a definition of a particular BME program [5,7]. The CRH-BME project group considered the results of these attempts as well as the current situation in the EU and the USA and recommended a set of seven *core topics* as the defining components of the BME curricula [10]. The term *topic* in this context is meant as a broader category than the term *course*. It means that in practice a *core topic* can be represented by more than one course in a curriculum, depending on the expertise and the objectives of a particular BME program. It is recommended that *at least* four *core topics* are covered in a considerable width and detail by any BME program, regardless of the type or the level of the study (1st or 2nd cycle). The core topics are:

a Biomaterials,
b Biomechanics,
c Biomedical instrumentation and sensors,
d Biomedical signal processing,
e Health technology design, assessment and management,
f Information and communication technologies in medicine and health care, and
g Medical imaging and image processing.

The CRH-BME documentation contains detailed descriptions of the core topics along with the general aim and the expected learning outcomes of each topic and with a sample syllabus of a course appropriate for each topic. The project documentation also provides an extensive and open list of elective topics, which can be used by BME programs to complete a BME curriculum [10].

3 THE BME PROGRAM AT THE FACULTY OF ELECTRICAL ENGINEERING, UNIVERSITY OF LJUBLJANA

A BME program is now included as one of seven stand-alone study programs in the 2nd cycle of the new modernized program at the Faculty of Electrical Engineering, University of Ljubljana. It will be first offered to students in the study year 2012/13 [4]. The BME curriculum has been designed by the Department of Biomedical Engineering which is also responsible for organisation of the curriculum. Other departments will be also contributing some of the BME courses. The entire curriculum of the BME program is shown in Table 2. The elective courses may be exchanged for courses from other non-BME study programs.

Table 2: The BME curriculum adopted at the Faculty of Electrical Engineering, University of Ljubljana. The labels co/el in front of the course name denote the compulsory and the elective status of the course [4]. The last two columns illustrate the compatibility of the curriculum with the CRH-BME recommendations regarding the content categories in Table 1 (column I) and the core topics from the generic curriculum in subsection 2.2 (column II).

Year, semester, course	ECTS	CRH-BME I	CRH-BME II
YEAR 1	***60***		
Semester 1	*30*		
(co) Biological systems	6	3,4	
(co) Biomedical informatics	6	2,5,7	d,f
(co) Measurements and sensors in biomedicine	6	2	c
(co) Biomedical electronics	6	2	c
(el) Numerical methods in electrical engineering and biomedicine	6	1,2	
Semester 2	*30*		
(co) Neurocybernetics	6	3,4	
(co) Biomedical signal processing	6	2	d
(co) Biomedical imaging techniques	6	2	g
(el) Robots in contact with humans	6	2,5	
(el) Biomechanics	6	2	b
YEAR 2	***60***		
Semester 3	*30*		
(co) Medical image analysis	6	2,5	g
(co) Data analysis and mining in biomedicine	6	2,5	d,f
(co) Bioelectromagnetics	6	2,4	
(co) Seminar in BME	6	5,7,9	
(el) Communication in science and research	6	6	
Semester 4	*30*		
(ob) Masters thesis	30		
TOTAL	**120**		

The adopted BME program is of type B as foreseen by the recommendations of the CRH-BME consortium (Table 1). This means that it is a stand-alone 2nd cycle BME program primarily intended to attract graduates of the 1st cycle engineering or physical sciences programs. The program is also harmonised with the CRH-BME recommendations in terms of the contents of its courses shown in Table 2. The numeric and alphabetic labels in the two right-most columns of Table 2 correspond to the content categories from Table 1 and to the list of core topics from subsection 2.2, respectively. Table 2 shows only the most obvious connections between the courses on one side and content categories or core topics. According to the CRH-BME recommendations, deviations in the number of credits within individual content categories may be up to 25% or ten ECTS creditsfor the BME program compatible with the criteria from Table 1. The curriculum also covers at least five of the seven core topics from subsection 2.2.

As this BME program will be running at the Faculty of Electrical Engineering, it is not surprising that the curriculum contains several courses which are related to electrical engineering, such as biomedical instrumentation and measurement, biomedical imaging techniques and biomedical signal and image processing. Such strong ties of the adopted BME program with one of traditional engineering disciplines is quite common at many universities. As the students expected to be enrolled in this program will in general possess only high-school level knowledge in biology and medicine, some advanced biological and medical topics are included in the curriculum, mostly in courses Biological Systems and Neurocybernetics, as well as in some other.

4 DISCUSSION

The industry of biomedical devices and other health-related products is among the fastest growing modern industries. Some of the important reasons for this phenomenon are the aging population and the growing incidence of various chronic diseases as well as the very rapid development of new technologies in this area. In the USA the occupation of biomedical engineer is expected to experience the highest relative growth (72%) in terms of new jobs available among all occupations until 2018. This projection was published by the Wall Street Journal [11] (citing from the latest version of the United States Department of Labor's publication, Occupational Outlook Handbook, 2010-11 Edition [12]). Furthermore, as many as eight out of the ten "hotest" occupations in the USA are connected to health care services. These data are summarised in Table 3 [12].

BME has a long tradition in Slovenia where the BME industry (although currently still relatively scarce) is one of the few industries developing, manufacturing and marketing its high-technology products all over the world. The so-called *Center of Competency - Biomedical Engineering* was founded on the Slovenian national level in 2011 [13] as a response of the Slovenian industry – small and large high-tech enterprises – to the challenges of the global market and the growing need of the local industry for biomedical engineers. The Center of Competency – Biomedical Engineering is a framework for collaboration on six development projects. It comprises all major players in the BME field in Slovenia: industrial partners (Fotona, Gorenje, Optotek, Iskra Medical, Instrumentation Technologies), both largest universities (University of Ljubljana with its Faculty of Electrical Engineering and Faculty of Mechanical Engineering, and University of Maribor with its Faculty of Electrical Engineering and Computer Science), the main research institute (Institute Jožef Stefan) and the three key medical institutions (Institute of Oncology Ljubljana, University Clinical Center Ljubljana, and University Rehabilitation Institute).

Table 3: Projected growth in the number of jobs for ten occupations with the fastest relative growth until 2018 in the USA [12].

Occupation	Educat. level	Growth (%)	New jobs (x1000)
Biomedical engineer	Bachelor	72	11,6
Network systems and data communications analyst	Bachelor	53	155,8
Home health aide	On-job training	50	460,9
Personal and home care aide	On-job training	46	375,8
Financial examiner	Bachelor	41	11,1
Medical scientist, except epidemiologist	Doctorate	40	44,2
Physician assistant	Master's	39	29,2
Skin care specialist	Special training	38	14,7
Biochemist and biophysicist	Doctorate	37	8,7
Athletic trainer	Bachelor	37	6,0

Next year, the BME field will find its deserved place in Slovenian higher education. In the first study year most students are expected to be graduates from the Faculty of Electrical Engineering of University of Ljubljana. However, we would like to attract graduates of other programs as well, such as mechanical and computer engineering, physics and others.

In the last years, we have been witnessing a steady decline in the number of students enrolled for the study of electrical engineering in Slovenia, a trend shared with other engineering disciplines. Formation of new attractive and up-to-date programs of high quality and responsive to the urgent needs of the modern society may be the right way to reevoke the interest of students in engineering in general and to attract more students to the study of electrical engineering. The growing concern of the modern society for the issues concerning the environment, energy and health will have to be reflected in the corresponding changes in the educational system.

The 2nd cycle BME study program at the Faculty of Electrical Engineering, University of Ljubljana, is the first such program in Slovenia. It is based on the long-lasting tradition of the BME field at the host institution and is built on the BME areas in which the research groups of the Faculty of Electrical Engineering have been successful. The program itself complies with the recommendations for adoption of new BME programs proposed by the CRH-BME consortium.

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BOOK REVIEW

Darko Kajfež, The University of Mississippi, Q Factor Measurements Using MATLAB®

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The book offers a systematic and detailed analysis of the theory and practice of measuring the resonator Q Factor. Since with high levels of the Q Factor it becomes difficult to separate the measurement loss from the inherent resonator loss, measuring the resonator Q Factor is not trivial. This book is an extension of the book Q Factor, 1994, and the bibliography of Professor Kajfež proves that he is one of the leading experts in resonators.

All the methods described in the book are based on the S parameter measurements using the vector network analyzer, and are distinguished by coupling of the resonator to the analyzer.

The book is divided into four chapters. In Chapter One, the author introduces theoretical grounds for the resonant circuits which are an imperative to understanding the resonator parameter measurements.
Chapter Two focuses on the method of measuring the resonator Q Factor using the measurement of the reflection coefficient.

With the method described in Chapter Three, the dielectric resonator is coupled to the microstrip line, while the resonator parameters are determined by measuring the transmission parameters.

Chapter Four is focused on determining the cavity resonator Q Factor using a pair of adequately coupled probes and measuring the transmission parameters.
Each chapter offers a detailed discussion of the error causes and the means of their correction. The book includes a DVD with software applications (MATLAB ver. 5 or later) that can be used to determine the resonator parameters from the network analyzer measurements.

This book is an indispensable aid to resonator measuring.