EDITORIAL BOARD

Polish Ministry of Science and Higher Education journal rating: 6.000
Sustaining institution: Ministry of Science and Higher Education
Edition: 300 copies

ISSN 1895-9091 (hard copy)
ISSN 1896-530X (electronic version)

http://www.bams.cm-uj.krakow.pl

The publisher: Księgarnia Akademicka, Kraków, St. Anny 6, Poland
http://www.akademicka.pl

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 5-6

BIOMEDICAL ENGINEERING EDUCATIONAL OFFER REVIEW

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Dear Reader

This issue of *Bio-Algorithms and Med-Systems* Journal is entirely dedicated to a review of educational offers in Biomedical Engineering from Polish Universities. Since the decree of Polish Ministry of Science and Higher Education issued in June 2006, first document listing the Biomedical Engineering (BME) as a separate academic domain, the education was implemented in 16 Universities throughout Poland. Now, with our first graduates and five years of experience, we, all the authors of included papers, found reasonable to present our approaches and ideas concerning the teaching. We hope that the education of bioengineers is an important concern for the *Bio-Algorithms and Med-Systems* Readers, not regarding whether their current position is BME professional or student.

Learning from best examples

Despite our formal education was in BME-related domains such as electrical, mechanical or material engineering, the tradition of BME research in Poland is nearly 100 years old. Using professional links established with best academic centers worldwide and applying the guidelines from International Federation for Medical and Biological Engineering (IFMBE) or Institute of Electrical and Electronics Engineers (IEEE) we became partners in international education conferences (e.g. BME-EDU 2001) and projects (e.g. BIOMEDEA Project 2005). International relations have also influenced the Educational Standard, elaborated in years 2004-2006 with a contribution from representatives of six Polish universities. Fortunately, the Standard includes only minimum teaching requirements and defines about 40% of the study track, while the remaining part allows the universities for adaptation to local opportuninties. The Reader will easily discover the specificity of each presented programme.

Sharing our experience

Diverse approaches and experiences need an efficient platform for integration and exchange. Initially this role was played by individual relations, but similarly to the research reports, organization of a biannual conference eased our contacts and experience sharing. Two editions of the National Conference on Education in Biomedical Engineering (pol. *Ogólnopolska Konferencja Inżynieria Biomedyczna - Edukacja*, *OKIBEdu*) brought together students, professors and industry representatives interested in improvement of domain-specific education problems. These meetings were starting points for several common projects in the areas of education and scientific initiation of students as well as opportunities for reinforcement of the academic-industrial relations influencing the job marked. It would be probably much more difficult to present the Educational Offer Review without the past *OKIBEdu* meetings, but we are already looking forward to host next conference in Krakow in 2012 (see cover page).

Dissemination of knowledge

Although dissemination of knowledge is an intrinsic part of professors' mission, in our case this idea has also a second meaning, since we present our approaches to BME teaching. In 11 papers presented, the Reader finds lot of concerns related to Biomedical Engineering and far more solutions proposed by professors from all over the country. We do not attempt to compare them, since they are all best fitted to local needs and conditions. Dissemination of knowledge has also its territorial aspect: Polish Universities opens their doors to foreign students and foreign employers vastly recruit from Polish graduates. This flow of human resources has a significant economical background and may be beneficial for our Universities. Consequently, many of them foster international staff and students exchange programs, adhere to international educational standards and use English as a lecture language for selected courses or for entire study tracks. This reason was also under consideration when we decided to bring our educational offers together as a review in English and to select the welcoming pages of *Bio-Algorithms and Med-Systems* Journal.

BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 7-9

INTRODUCTION TO THE REVIEW OF EDUCATIONAL OFFER IN THE FIELD OF BIOMEDICAL ENGINEERING IN POLAND

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Abstract: In the article the short history, development and introduction to the review of the educational offer in the field of biomedical engineering in Poland were described. The situation of the scientific discipline named biocybernetics and biomedical engineering and development of the clinical profession called medical engineering were also presented.
Keywords: biomedical engineering, educational offer.

Reviewing the condition of education in Poland is highly interesting, but above all, may be useful for the potential candidates, as well as for the universities, intending to open this attractive field of study.

After putting Biomedical Engineering on the list of fields of study 4 years ago, what was possible due to the joint efforts of six technical universities (as the applicant – prof. Ryszard Tadeusiewicz from the University of Science and Technology in Cracow, and supporting universities: of Warsaw, Łódź, Wrocław, Gdańsk and Silesian University of Technology), the time has come to review the previous experiences and evaluate program and organization of education in the field of Biomedical Engineering.

Education in specializations similar to Biomedical Engineering, but with different programs are also conducted by several other technical universities in Poland, not fulfilling staff requirements.

The initiative of discussion on improving programs and ways of training in the area of biomedical engineering at the universities conducting this field of study, is of a great importance.

The established field of study sets certain conditions for curriculum and staff, that have to be fulfilled in order to enable the university to conduct this specialization. There is, however, a certain margin of freedom in the choice of study program and its content. The question is how to take advantage of this freedom.

Is it better to unify the training or differentiate it, using the specificity of the university and faculties, their traditions and staff resources? Biomedical Engineering is an interdisciplinary field of study. Differentiation will increase graduates' adjustment to the labor market, and also extend the educational offer.

Although the formal establishment of Biomedical Engineering as a field of study had place not so long (just 4 years) ago, it is worth recalling that it had already existed under the name of Biocybernetics and Biomedical Engineering at the Warsaw University of Technology (years 1990 -1995). It was based on an existing since 1946 specialization of a medical engineering nature (elektrotechnika medyczna), which for years have taken different names, initially as medical nuclear electronics at the Faculty of Electronics. The creator of this specialization (organizer and applicant) was professor Cezary Pawłowski, head of the Department of Physics at the Radium Institute.

It was then the world's first organized form of higher education for physicists and medical engineers.

Professor Cezary Pawłowski, who later became mentor, supervisor and boss of prof. Pawlicki, which he was an assistant of in the years of 1959 – 1965, worked as a lecturer in the department of Experimental Physics led by prof. S. Pieńkowski at the Warsaw University. In 1927 he was sent for, as we would call it today, the six years' training to the laboratory of Maria Skłodowska – Curie at the Sorbonne. The aim of this training was to prepare him to take up a position of a director of the Department of Physics in the Radium Institute, which was about to be created at the initiative of Maria Skłodowska-Curie in Warsaw. When the institute was finally established in 1934, prof. Pawłowski organized the Department of Physics and took over its management.

After the war, prof. C. Pawłowski returned to the position of a director of the Department of Physics in the Radium Institute and surprisingly he turned out not to Warsaw University where he originated from, but to the Warsaw University of Technology, with the request to start the system of educating engineers for the purposes of medical institutions.

It was a surprising, but far-sighted decision, because at that time only medical physicists took care of the equipment used in medicine. The beginnings of the development of technical (physical) measures we owe to medical physics, the history of which reach a long time backwards. There is no exaggeration in stating that its history is as long as the history of medicine.

If you take the definition of engineering as the ability to design, construct and use of devices, then those applied in medicine, were originally (XVII-XIX century) operated by physicists.

However, the great discoveries made at the turn of the XIX and XX centuries: the X-ray (1895, K.W. Rentgen), the radioactivity of uranium, radium and polonium (1898, Becquerel, M. Skłodowska-Curie and P. Curie) and recording the electrical heart activity (1903, W. Einthoven), immediately applied in medical practice, caused great interest of medicine and led to their production on a large scale. Here, the engineers were needed. This moment can be considered as an isolation of medical engineering out of medical physics, that is the birth of biomedical engineering, and later, in an abbreviated form, after dropping the suffix "bio", related to engineering applications in biology .

Undoubtedly this moment was the beginning of the intentional and directed development of medical devices: diagnostic (X-ray techniques, electrocardiography and electroencephalography) and therapeutic (electro- and light therapy, orthopedic and rehabilitation devices.)

Organizational foundation of the specialization "medical electrical engineering" established in 1946 by prof. C. Pawłowski were two departments: the Department of Radiology, led by prof. C. Pawłowski until his retirement in 1970 and the Department of Electrical Engineering Devices, headed by an eminent engineer, previously employed in the factory of X-ray equipment in Warsaw – Stanisław Nowosielski. The Department has also hired another outstanding engineer in the field of electronic devices – prof. Juliusz Keller (constructor of stereovectograph together with prof. Jan Kwoczyński, and prof. Juliusz Ekiel, State Prize winners for this invention).

After separating the Department of Communications out of the Department of Electrical Engineering, electrical medical engineering as a specialization moved into a new faculty and transformed into electrical engineering in medicine and radiation (at that time there were great opportunities to application of radioactive isotopes in medicine, beyond main military application).

Military applications and radiological protection turned out to be more important and at the opportunity of organizational changes (creating institutes in place of departments), some of the specializations related to electrical medical equipment, were transferred to the Faculty of Precision Mechanics (!) of Warsaw University of Technology (currently the Faculty of Mechatronics). Prof. G. Pawlicki was angaged there in 1970, and as the time went by replaced prof. Stanisław Nowosielski, after his retirement, as a director of the Team of Electronic Medical Equipment in the Institute of Precision and Electronic Equipment (!). The concerned area has been extended to issues of precision – mechanics (e.g. sensors), optics and lasers that could be used for medical purposes.

The second centre in the country undertaking in 1969 education in the field of biomedical engineering at the higher (university) level, was Silesian University of Technology (doc. J. Kopka and doc. Kwieciński). Almost at the same time (the beginnings of the seventies of the twentieth century) education in biomedical engineering was introduced in Wrocław University of Technology (prof. Zbigniew Karkowski and doc. Hanna Karkowska).

Specialization of biomedical engineering began to develop rapidly in the seventies. In 1972 the Committee of Biocybernetics and Biomedical Engineering was established at the Polish Academy of Sciences, Department IV of Technical Sciences, and then the Institute of Biocybernetics and Biomedical Engineering at the Polish Academy of Sciences in Warsaw. Scientific and didactic issues, corresponding to the area of knowledge in the field of biomedical engineering, have taken a few centers in the country. In addition to the Warsaw University of Technology, strong centers were created in the form of the University of Science and Technology in Cracow, Wrocław University of Technology, Cracow University of Technology, Silesian University of Technology in Gliwice, Gdańsk University of Technology and many other universities.

During this period, biomedical engineering has developed dynamically both in terms of scientific and educational areas, not only at the Faculty of Mechatronics of Warsaw University of Technology (where the Institute of Biomedical Engineering was created – prof. T. Pałko), but also at many other technical universities in Poland, as a specialization within different fields of study. There were formed different departments of Biomedcial Engineering (Gdańsk University of Technology – with its director prof. Nowakowski), Interfaculty School of Biomedical Engineering (at the University of Science and Technology in Cracow – director-ass. prof. P. Augustyniak) and numerous Institutes of Biomedical Engineering. Interest in studying at these specializations was increasing, together with the number of highly qualified, scientific and didactic, staff.

In the eighties, the Team of Electronic Medical Equipment changed its name into the Department of Biomedical Engineering (with its director prof. G. Pawlicki, WUT), which was a fashionable term abroad. In Poland, for several years, the term was present only in the name of the newly created Institute of Biocybernetics and Biomedical Engineering, established by prof. M. Nałęcz in 1975 at Polish Academy of Sciences and a main subject in the scientific research. In higher education, this term appeared first in the form of the name of the department and at the same time – teaching specialization.

In 1989 joint efforts of the Faculty of Precision Mechanics (Prof. G. Pawlicki, Prof. T. Pałko) and the Faculty of Electronics (Professor Z. Pawłowski) with the support of prof. Nałęcz – head of the Institute of Biocybernetics and Biomedical Engineering of Polish Academy of Sciences, led to acquiring the status of a field of study, which was closed shortly after the political transformation in 1990.

In the mid nineties the Faculty of Mechatronics, obtained the right to grant a doctoral degree in the field of biomedical engineering, and from 30th September 2002 also to grant associate professor degree. These rights had also contributed to the formal development of biomedical engineering at other faculties of Warsaw University of Technology and other Universities.

Currently almost all of the universities have institutes, departments or scientific-didactic units, whose activity is closely related to research in biomedical engineering. It should be noted that three of these universities have the authority to grant doctoral degree (the University of Science and Technology in Cracow, Silesian University of Technology and Warsaw University of Technology), out of which WUT and Silesian University of Technology have also the authority to grant an associate professor degree in the discipline of biomedical engineering.

The role and importance of biomedical engineering in the health care system must have reached doctors' awareness much later. The development of technical means of diagnosis resulted in the doctors' interest in the reliability of the obtained data on the structure and functioning of internal organs, with the use of sophisticated and complicated equipment to complex diagnostic imaging (classic radiography, nuclear medicine, tomography CT, MRI, PET, ultrasound, etc.).

Mistake in the results obtained by using modern means of diagnosis can be just as serious as overdosing or using too low dose of radiation. Misdiagnosis of anatomical changes or wrong evaluation of the organ or tissue functions entail disastrous consequences. Equipment must be monitored and tested, and the obtained results – verified in a continuous manner in the operating conditions. The presence of physicist or engineer in the medical team became indisputable.

The formal evidence of this belief was the Regulation of the Minister of Health of 17th October 2002, on obtaining the title of specialist in the fields applicable in health care. Among these are the professions of medical physicist and medical engineer.

In the Annex to this Regulation we can find a list of professions allowed to obtain such title of specialist, in the field of professional medical engineering.

Those wishing to practice such professions should get appropriate higher education degree in, respectively, medical physics and biomedical engineering or in the fields of study that carried out or are currently carrying out biomedical engineering specialization. Then they should undergo postgraduate training on licensed (by a program approved by the Ministry of Health) specialization studies "in the field of medical engineering."

The proof of a very serious treatment of these professions was the establishment of the position of national and provincial consultants in these areas.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 11-20

MULTIDISCIPLINARY BME TEACHING – A RECTOR'S POINT OF VIEW

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Abstract: Paper presents general overview of the tradition of Biomedical Engineering research and education in AGH University of Science and Technology (AGH-UST), expressing special role of inter-faculties agreements. On the basis of this agreements Biomedical Engineering teaching was established on the form of Multidisciplinary School of Engineering in Biomedicine (MSIB) was constructed together by five faculties of AGH-UST: Faculty of Electrical Engineering, Automatics, IT and Electronics (EEACS&E), Faculty of Materials Science and Ceramics (MS&C), Faculty of Mechanical Engineering and Robotics (ME&R), Faculty of Physics and Applied Computer Science (P&ACS) and Faculty of Metal Engineering and Industrial Computer Science (ME&ICS). Because of such origins of Multidisciplinary School of Engineering in Biomedicine and because of related to this set of founders structure of teaching processes in these School we can educate our students, further biomedical engineers, in rather wide areas of competences. The story of Multidisciplinary School of Engineering in Biomedicine in AGH-UST is presented from rector's point of view, because author of the paper was rector of AGH-UST when MSIB was founded and developed.
Keyuwords: Biomedical Engineering, new faculty forming, teaching in multidisciplinary areas, AGH-UST

Introduction

Biomedical Engineering is a discipline which has recently become very trendy. After a period of relative stagnation, when all other branches of technology such as industry, weapons production and economy exhibited a steady or even accelerated growth, there came a moment when a large number of researchers realized that many fascinating scientific challenges can be found in Biomedical Engineering (Fig. 1).

What is also worth noting is that medical bioengineering not only helps to provide solutions to technical and/or scientific problems focused on the important goal of human health care in general and treatment of diseases in particular, but also offers opportunities to reap large financial benefits, especially when new inventions are commercialized and production is started. One should be aware of the fact that regardless of possible economic and political fluctuations, human needs in health care are unlimited and are always rising. That is why the demand for new techniques in all other various branches of technological applications may either grow or fall, whereas that in medical engineering will only be on the rise. This fact is strictly connected with the ever-growing population of elderly people (Fig.2), who are more and more in need of medical services, including those that are to a greater or smaller extent dependent on the products produced or serviced by specialists trained in Biomedical Engineering. It should be noted that the above trend, based on data supplied by the World Health Organization, clearly shows that Poland falls behind other EU countries, which brings about consequences of two kinds. Firstly, it can easily be seen that Poland's needs to develop and improve the national health care system are urgent and significant, including the need to develop a technical powerbase for medicine, so that the civilization gap between this country and the rest of Europe is quickly bridged. Secondly, the prospective demand for Biomedical Engineering products, which is even stronger in other more prosperous countries than it is in Poland, may create a sizable market for Polish products and services.

All of the above-mentioned scientific, economic and social considerations bring us to the conclusion that the demand for specialists educated and trained in Biomedical Engineering will undoubtedly increase in the future. This fact has been fully understood in Poland, and therefore studies in Biomedical Engineering have been started relatively early in this country following the example of similar studies traditionally implemented in many universities or other schools of higher learning abroad (Fig. 3).

Fig. 1. Research and development (R&D) in Biomedical Engineering are being carried out across the world (source: http://www.studydiscussions.com/wp-content/uploads/2010/04/Biomedical-Engineering12.jpg, access August 2011)

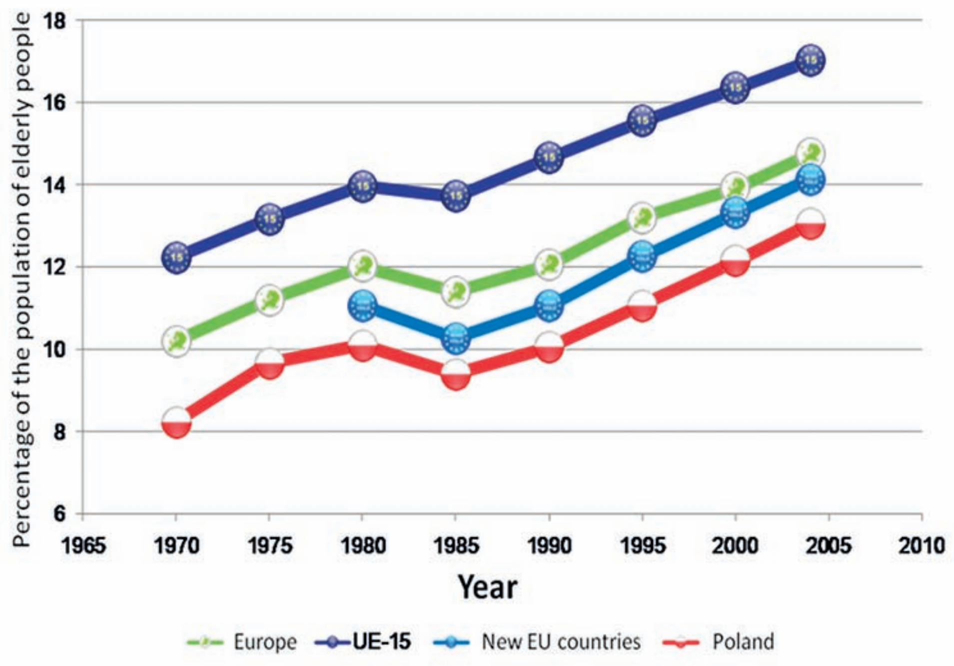

Fig. 2. Percentage of the population of elderly people in Poland and in other EU countries. Source [1]

Unfortunately, the path leading from the intention to initiate Biomedical Engineering studies and later put them in practice has been quite long and often difficult.

Now when Biomedical Engineering has become a generally recognized and accepted specialty and almost all technical universities or colleges have incorporated it in their curricula and syllabuses, all of this seems simple and obvious.

However, the beginnings were not always easy and straightforward, and therefore it may be worth giving some thought to the beginnings of the education in Biomedical Engineering in Poland, as it is only by referring to the origins and the history of this specialty's development that the future of Biomedical Engineering can be better understood and ensured.

A cumulative paper or report on education in Biomedical Engineering describing the past, present and future development of this branch of science and technology in Poland may, or should perhaps be presented in future. This paper, however, does not aspire to become such a wide-ranging presentation since it is based on a single case of teaching Biomedical Engineering at the AGH University of Science and Technology (AGH-UST) in Cracow (Poland), which was the first to initiate this novel specialty in this country. Our concise and probably more subjective history of Biomedical Engineering at the AGH-UST seems to provide only a small contribution to the above-mentioned objective. It does, nevertheless, seem to have achieved one quite significant success, i.e. the foundation of a Multidisciplinary School of Engineering in Biomedicine (MSIB), responsible for teaching in the field of Biomedical Engineering, based on the material and human resources of five Faculties of AGH-UST (Fig.4). This made it possible to provide multidisciplinary education.

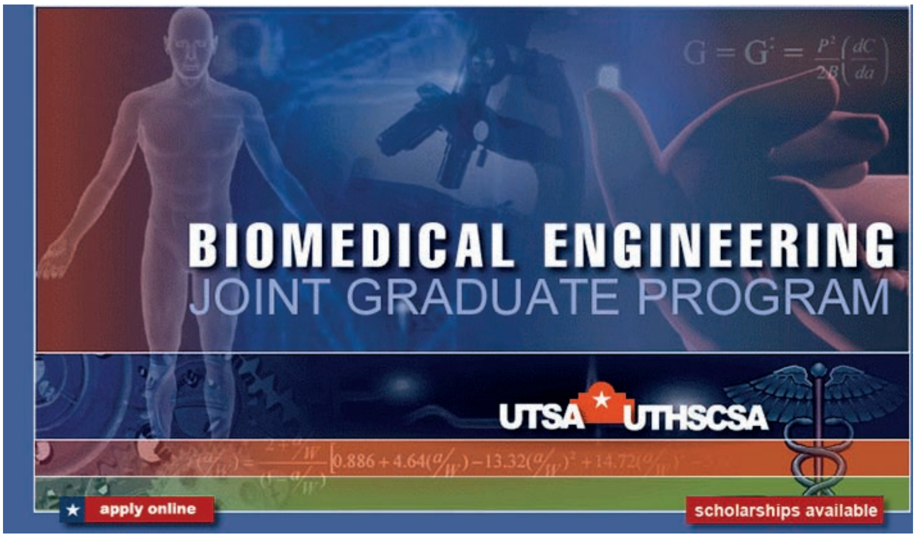

Fig. 3. An example of an education scheme in Biomedical Engineering
(Source: http://engineering.utsa.edu/bme/BME_program/, access August 2011)

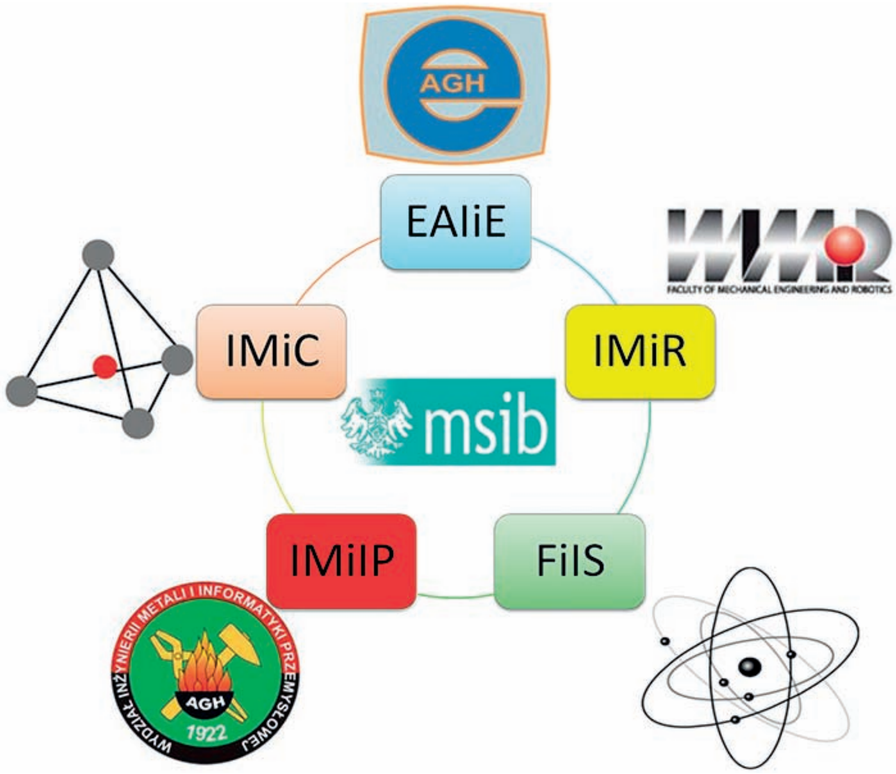

Fig. 4. Faculties jointly responsible for the foundation of **MSIB**
(Multidisciplinary School of Engineering in Biomedicine – MSIB). Description of abbreviations:
IMiIP = Faculty of Metal Engineering and Industrial Computer Science (ME&ICS),
EAIiE – Faculty of Electrical Engineering, Automatics, IT and Electronics (EEACS&E);
IMiC = Faculty of Materials Science and Ceramics (MS&C);
IMiR = Faculty of Mechanical Engineering and Robotics (ME&R),
FiIS = Faculty of Physics and Applied Computer Science (P&ACS)

What should be noted here is that the joint responsibility of these five Faculties in establishing the foundations of the MSIB is a distinguishing factor among other Polish universities or institutions of higher learning which have also started Biomedical Engineering education and training.

Multidisciplinary approach as a distinguishing feature of the MSIB

In most universities, education in Biomedical Engineering is taught at one specific faculty representing a well-defined scientific profile based on a long tradition of teaching in this particular field and/or related subjects. In this situation, Biomedical Engineering as an additional subject of study tends to select and favor a set of problems within the field of interest of specialists working in that particular Faculty. This approach has its advantages, too, since the educators teach their own subjects in which they are confident and well-specialized, and they can combine lectures with laboratory exercises that used to be employed in teaching previously, eg. basic electronics or industrial automation. However, the weak point of such an approach is that the wide spectrum of problems involving the present-day Biomedical Engineering becomes limited to the elements that are adapted to the preferences of the teaching staff rather than to those which are objectively most needed in Biomedical Engineering curricula.

Fig. 5. Rector of the AGH-UST, Professor Ryszard Tadeusiewicz, signs the MSIB foundation act (2005)

By establishing the Multidisciplinary School of Engineering in Biomedicine at the AGH-UST (Fig. 5), opportunities were opened to provide education on a very wide spectrum of subjects thanks to the large and varied personnel resources of five Faculties of the AGH-UST (see Fig. 4). This was made possible, among other things, to the fact that at the initial stage of the foundation of the MSIB, the author of this paper held the office of the Rector (President) of AGH-UST and in this position was able to persuade the Deans of all the five Faculties to take up a common initiative even at the cost of relinquishing some of their individual benefits and powers. As a result, a really multidisciplinary school could be created in the form of the MSIB offering education in theoretical and practical technology combined with medicine. Below is a list of tracks or specialties offered to the students in the Second Degree (Master's) programme:

– Medical Information Science and Electronics;
– Biomaterials Egineering in Biomedical Engineering;
– Biomechanics and Robotics;
– Bionanotechnologies;
– Emerging Health Care Technologies.

These wide-ranging multidisciplinary curricula are the best evidence of the success of the AGH-UST in starting the MSIB. This is also the reason why, despite the generally smaller number of first-year university students due to the demographic decline in Poland, the MSIB still enjoys an influx of an increasing number of very good candidates who in order to fulfill admission requirements of the MSIB usually achieve a very high score on their General Certificate of Education (so-called "matura"). For instance, in the academic year 2011-2012, this was 821 points (out of a maximum of 1000).

This success was made possible by the fact that prior to setting up the MSIB, scientific research and some forms of education in Medical Engineering had also been carried out and taught at many other Faculties of the AGH-UST.

The legendary "prehistory" (hypothetical) of the relationships between biomedical engineering and the AGH-UST

As early as 1919 and even earlier, all those employed at the AGH-UST from the very moment this institution was founded, were to provide the medical profession with all the possibilities involved with the advances in science and technology of the time. Naturally, there were different kinds and forms of the "advances" depending on the historical period, therefore the range and the character of technological support changed from one moment to another. However, the AGH-UST as an education and research institution was always proud to offer the medical world the best, up-to-date and prospectively promising achievements that they could possibly have.

Now we could describe a rather hypothetical situation involving Biomedical Engineering belonging to the early years of the AGH-UST. If we turn to Fig. 6 we can easily see that in the photograph taken in the year 1911, Maria Sklodowska- Curie (first from the left) is shown with her daughter Irene (also future Nobel Prize laureate) and Professor Walery Goetel (in a striped shirt), future Rector of the Mining Academy (now AGH-UST). Of course we have no idea what the conversation between these people was about, but surely it was not only concerned with the beauty of the mountain scenery around them. As reported by Marie Sklodowka-Curie's younger daughter, Eve, in her book [2], Marie on various occasions, even in family conversations with her children, used to talk on professional topics. A similar tradition of "talking shop" at home has been passed down in Prof. Goetel's family [3]. It could well be that the conversations between these two famous scientists during their joint mountain trips or family meetings (Prof. Goetel's wife was Maria Skłodowska, Marie Sklodowska-Curie's brother's daughter) led to Marie's decision to expand her interest in the chemical and physics aspects of radioactivity and discovery of new elements into the area of practical application of her research. In that same year 1911 (i.e. when the above photograph was taken), Marie Skłodowska-Curie persuaded the French government to invest money in the foundation of Institut du radium (now Institute Curie) in Paris with its mission of research in the application of radioactivity for the medical treatment of cancer. Marie's work, among other things, in the use of radioactive elements in medicine, has opened up a new branch of medical science and practice, i.e. radiotherapy [4]. It may be that her discoveries related to the application of radium in the therapy of cancer can be traced back to those conversations in the Tatry Mountains…

Fig. 6. Probably one of the earliest photographs of the meeting dated 1911 and laden with consequences between Maria Sklodowska Curie (first from the left), a double Nobel Prize laureate and professor at the Sorbonne (Paris), and Walery Goetel (first from the right), professor and future rector of the Mining Academy (now the AGH-UST), on a mountain trip (photograph courtesy of Prof.Goetel's family).

Fig. 7. Irena (daughter) and Maria Curie while operating an X-ray unit (Source: http://nobelprize.org/nobel_prizes/chemistry/laureates/1935/curie_marie_irene_hospital_photo.jpg access August 2011).

It was during World War I that Marie Sklodowska-Curie showed a real and practical interest in biomedical engineering. After the outbreak of the war in 1914 Maria Curie, who was still heading *Institut du Radium*, decided to get personally involved in saving the lives of soldiers at the German-French front. She was instrumental, as Director of the Red Cross Radiology Service, in creating French Renault trucks converted into ambulances, equipped with mobile radiology units. These cars, called "petite Curie," transported X-ray apparatus to the wounded at the battle front. In total, 20 such mobile radiology units were set up, and Marie together with her daughter Irene operated the then state-of-the art biomedical X-ray machines, while all the time personally exposed to the same dangers and inconveniences as the fighting soldiers (Fig.7).

We shall never know to what extent Marie's new experiences were due to her earlier conversations with Walery Goetel. However, the very fact that Marie's interests became transferred, as it were, from "pure" science to applied science and medical technology, undoubtedly originated in 1911, as corroborated by many credible sources.

The origins of Biomedical Engineering at various Faculties of the AGH-UST

As I mentioned earlier, we shall never know whether Marie Sklodowska-Curie was "bitten" by the biomedical bug during her personal contacts with the future Rector of the AGH-UST. However, we have full knowledge of how the "bug" caught on and was alive at five Faculties of the AGH-UST, which took a courageous decision to jointly establish a Multidisciplinary School of Engineering in Biomedicine (Fig. 4). Let us start with the Faculty of Electrical Engineering, Automatics, Computer Science and Electronics (EEACS&E) and then we shall go round a ring depicted in Fig.4 indicating (in a very short form) some selected facts related to our field of interest.

Fig. 8. Early works involving Biomedical Engineering at the EEACS&E faculty (source: author's own materials)

It seems that it was as early as 1970s that the EEACS&E faculty became interested in Biomedical Engineering. It is quite possible that one could find some earlier works published in this field, but as a result of the search carried out by the author of this paper, it may well be that the first ever paper on biocybernetics carried out at the EEACS&E Faculty was that quoted in Literature as [5] and one directly on Biomedical Engineering was the article [6]. It is of interest that the title of this paper [6] did not include the word "computer" since at that time this term was not yet in use in the Polish language, instead we had a word "electronic digital machine", literally translated from Russian. It is worth having a look at Fig.8 which shows how data and programs were being introduced to "digital machines". Programming was carried out in the so-called internal computer language and the operation involved setting up binary codes on the keyboard (in the background of the photograph). The positive results thus obtained to determine the consequences of radiotherapy with the use of image visualization were in themselves quite a success.

As mentioned earlier, there is no guarantee that papers [5] and [6] produced at the EEACS&E faculty were truly the first ones dealing with Biomedical Engineering since some authors may have published their work earlier, but our quick search has not proved otherwise. On the other hand, the first textbooks on Biomedical Engineering issued by the AGH-UST and implemented in teaching programs were those shown in Fig. 9 [7, 8]. This can be proved beyond any degree of doubt, since there exists a full list of books published by the AGH-UST since the foundation of the Academy in 1921.

In the 1970s, Biomedical Engineering successfully developed at the EEACS&E faculty. In 1973, an Independent Biocybernetics Laboratory at the Institute for Informatics and Automation was set up. Biocybernetics and Medical Electronics were included as specialized teaching topics in the Automation and Electronics tracks. Close co-operation was established with the Medical Academy, which, among other things, resulted in having books which had been prepared by AGH-UST authors published by the Medical Academy to be used as teaching materials for medicine students. This was seen as a form of introduction to their future role of physicians and users of Biomedical Engineering products. (Fig. 10). At the same time, the first ever teaching programme was designed and developed jointly by the AGH-UST and the Medical Academy to educate specialists later to be employed as biomedical engineers. Unfortunately this programme could not be implemented at that time, but it served as a basis to set up the presently used biomedical engineering curricula at the MSIB.

Unfortunately, in the 1980s advances in scientific research in Biocybernetics and Biomedical Engineering as well as teaching programs at EEACS&E were brought to a stop. This was, to a large degree, a consequence of the critical attitude of the Faculty Dean at the time. When in the late 1980s, the EEACS&E hosted the 7th National Conference on Biocybernetics and Biomedical Engineering, the Faculty Dean stated in reference to the opening paper entitled "Fifteen Years of Biocybernetics and Biomedical Engineering in Kraków" that the whole "business" of Biomedicine stands no chance of development at the AGH-UST because *tour institution has always been and will be an Academy of Coal and Steel*".

The early 1990s brought a change in those who were in charge of the EEACS&E Faculty, with a revival of interest in Biomedical Engineering. The Departments which until then had dissociated themselves from this field of interest, now started to slowly contribute to research and teaching in biomedical engineering by, among other things, organizing specialist scientific conferences. The most notable example of this kind of action involved the Department of Metrology, which at that time played the role of national leader in some branches of Biomedical Engineering. In this context what is perhaps worth mentioning is an annual conference entitled "Modelling and Measurements in Medicine" taking place over the past 10 years and hosted by the Department of Metrology as a forum for exchange of experience and information in bio-measurements. Again, the Department of Automation (together with the Collegium Medicum of the Jagiellonian University in Cracow) has been organizing scientific conferences entitled "Cybernetic Modelling of Biological Systems" since 1979.

The ever stronger tendency to find common elements of biology and medicine on the one hand and automation, electronics, informatics and telecommunications, i.e. traditional fields of interest of the EEACS&E Faculty, on the other, has found its finale in the setting up of the MSIB. It was at the EEAICS&E Faculty that most specialists were ready to pursue their teaching and research activity in connection with Biomedical Engineering, which, as a consequence, provided teaching staff for the newly founded Multidisciplinary School.

The Faculty of Materials Science and Ceramics (MS&C) was another Faculty which can be found (shown in Fig.4) among those contributing to the establishment of the MSIB. This faculty started its activity in Biomedical Engineering in the early 1980s, first by focusing on carbon implants in orthopedics and ceramic materials in dentistry. Later the scope of its research was systematically enlarged to encompass design, production and investigation of materials used in the treatment of pathological tissues. In particular, since the 1980s, investigations have been carried out on ceramics implant materials based on calcium phosphates (CaPs) at the Department of Ceramics and Fire-Resistant Materials at the Faculty of Materials Science and Ceramics. These investigations have led to the development, biological tests and industrial-scale implementation of the first ever in Poland hydroapatite (Hap) and two-phase Hap-TCP implant materials. Implants varying in shape (dense, porous, granules and powder) have been successfully tested over many years, some of them having even passed medical attestation. As an example, a typical implant product resulting from the work of the MS&C Faculty is shown in Fig. 11.

What is interesting and very significant is that the biomaterials research developed at the MS&C Faculty included study of practically all material groups such as ceramics, polymers, composites and metals. The results of these investigations are presented at a national conference on "Biomaterials in Medicine and Veterinary Medicine" held in Rytro every year for the past 20 years. It should also be mentioned that these conferences, which target physicians and engineers involved in the study of biomaterials as well as corresponding institutions representing the Polish medical industry, have led to the foundation of the Polish Society for Biomaterials in 1995, a member of the European Society for Biomaterials, located at the MS&C Faculty and as such is an important component of the Polish biomedical engineering community. Following the initiative of the biomaterials study group at the MS&C Faculty, a bilingual Polish-English scientific journal

"Engineering of Biomaterials" started to be published with the Editors' Office located also at the MS&C Faculty.

One should also mention a research team responsible for the development of implants based on carbon components. This team became internationally recognized, and, as a result, was entrusted with the task of organizing a World Conference on Carbon in 2012 in Kraków.

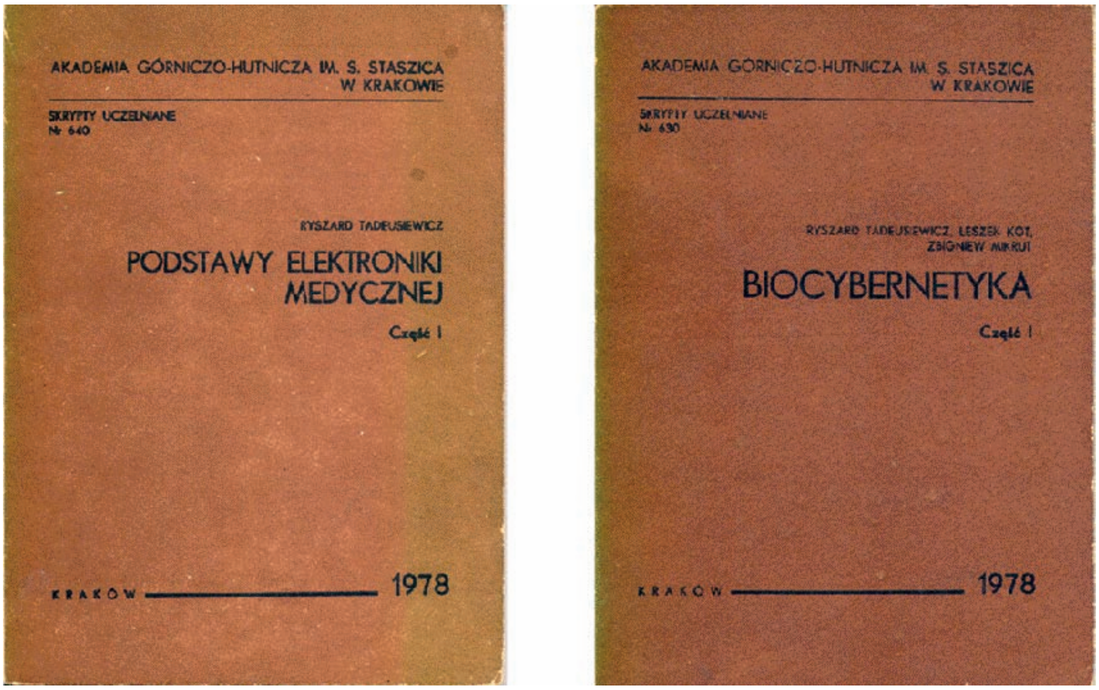

Fig. 9. The first Polish textbooks for biomedical engineering students issued by AGH-UST

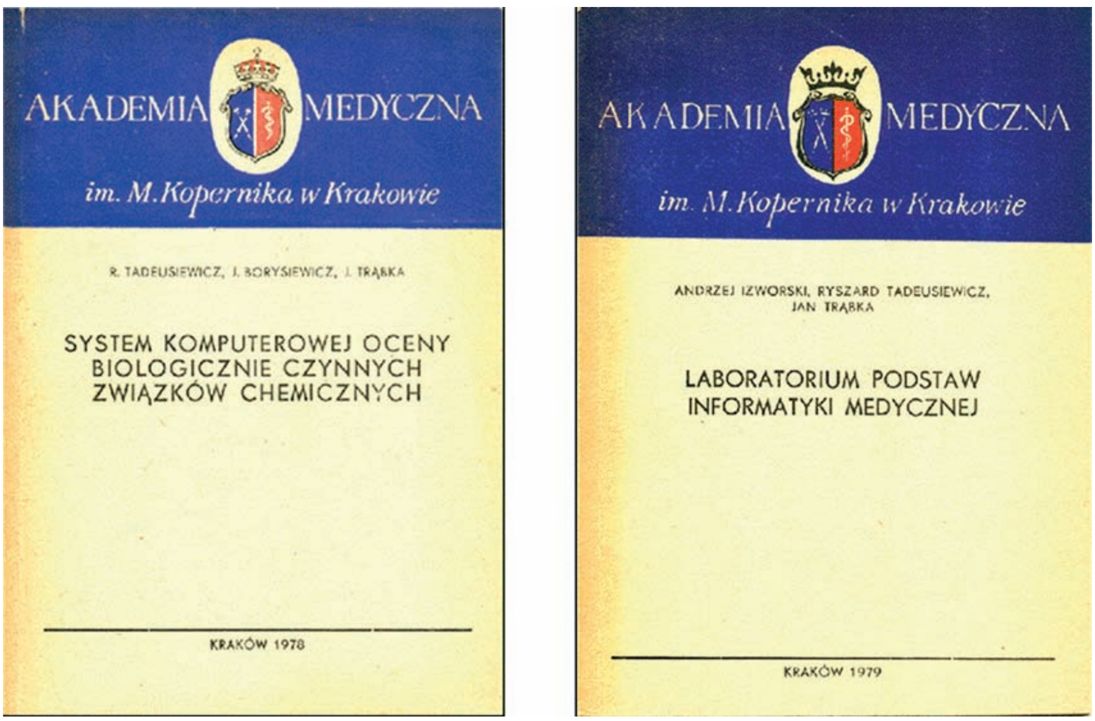

Fig. 10. The first textbooks on Medical Informatics
prepared by AGH-UST staff and published by the Medical Academy

In addition to MS&C's valued scientific achievements in Biomedical Engineering, work has also been carried out in this Faculty to educate and train students. In the early 1990s, a "Biomaterials and Composites" teaching specialty was initiated in the form of lectures, laboratory courses, seminars, etc. both as obligatory and/or optional requirements. At present, this form of education and training contributes to the success of the " Multidisciplinary School of Engineering in Biomedicine.

Fig. 11. A typical implant product resulting from the work of the MS&C Faculty

In 2003, by the decision of the Senate of the AGH-UST, a new organizational unit, the Department of Biomaterials, was set up at the Faculty of MS&C. This was a result of research studies and teaching activity in biomaterials carried out over a number of years at the Faculty of Materials Science and Ceramics.

Another Faculty depicted in Fig.4 is that of Metal Engineering and Industrial Computer Science ME&ICS. The history of Biomedical Engineering at this Faculty is shorter than that at the MS&C Faculty. However studies have been carried out at this Faculty at the Department of Metal Science and Powder Metallurgy since as early as 2001. This work was mostly done on microstructures and properties of titanium biomaterials, which was justified above all by the good anticorrosion properties of titanium biomaterials in a tissue and biological liquid environment and by a better bio tolerance of implants as compared with other biomaterials. What was also important was a lower specific density and good mechanical properties of such materials.

Along with research on titanium with the view of potential application in medicine, the Faculty of Metal Engineering and Industrial Computer Science was also concerned with cobalt alloys and other shape memory alloys, various kinds of steel, tantalum and its alloys, plastics, bioceramic materials and carbon plastics. This research was inspired by the fact that metals and their alloys, due to their good mechanical properties, are suitable long-term implant materials and they can be used in instruments and special tools in medicine.

It is not only biomaterials as such but also the processes of their formation that were investigated at the ME&ICS Faculty. In medicine, implants and other elements are produced by specialized techniques such as casting into special forms, plastic processing (penning and rolling) with the use of various mechanical, chemical and thermal surface finishing technologies. Other problems were also investigated such as finding suitable properties of surfaces and near-surface layers, the so-called implant outer surfaces, which, in the process of casting, fail to acquire optimum properties. This in turn may cause infections and allergic reactions, and finally lead to implant rejection by the body.

Another Faculty responsible for establishing the Multidisciplinary School of Biomedical Engineering is the Faculty of Physics and Applied Computer Science (P&ACS). Since the very beginning of its foundation (1991), this Faculty has always been concerned with research which directly or indirectly involved biomedical engineering.

To be more exact, studies of this kind had been conducted earlier, as the physics community at the P&ACS Faculty have initiated various investigations involving animate matter since the foundation of AGH-UST. In fact, they had shown interest in medical problems as early as 1965 when the Polish Society of Medical Physics came into being, some of physicists being among the Society's founding fathers. However, in this paper we are not concerned with education in the framework of Medical Physics as it is disparate from the Biomedical Engineering education at the MSBE discussed in the present paper, therefore in what follows we shall not pursue this historical subject.

The last Faculty cooperating in setting up the MSIB was the Faculty of Mechanical Engineering and Robotics (ME&R). Studies involving Biomedical Engineering have been conducted at this faculty since the mid-1990s, for the most part focusing on vibroacoustic signals treated as a source of diagnostic information, at least at the beginning. What should be particularly noted here are internationally recognized studies on the analysis of pathological speech signals. Other problems under investigation at the ME&R Faculty were models of the hip joint, tribology, prosthetics, etc. from a wide spectrum of biomechanics.

Biomedical Engineering at the ME&R Faculty started to enjoy a significantly greater interest when the Laboratory of Structural Acoustics and Biomedical Engineering came into being at that Faculty in 1995. The Laboratory focused its investigations mainly on the effect of elastic waves on living organisms. What is also worth mentioning is the organization of annual conferences devoted to Acoustic Methods in Biomedical Engineering; the title of these conferences often changed, sometimes referred to as " Structures-Waves-Biomedical Engineering ", but it was always continued in the traditional line.

Specific areas covered by Biocybernetics and Medical Engineering developed at various Faculties of the AGH-UST

The above mentioned discussion is related to the history of Medical Engineering at various faculties of the AGH-UST. The following chapter will in turn be concerned with the current state of affairs in this field. We shall again refer to Fig. 4 and shall describe activities in each Faculty jointly combined into the Multidisciplinary School of Biomedical Engineering.

The issues investigated at the EEACS&E Faculty involving Biomedical Engineering may find their place in the following fields:

- Biocybernetics as a theoretical and conceptual basis for the development of Biomedical Engineering;
- Digital analysis and processing of biomedical signals;
- Medical imaging and computer techniques for processing; analysis, recognition and automatic understanding of medical images;
- Design, construction and optimization of medical equipment;
- Application of present-day informatics, especially artificial intelligence (AI), in medicine;
- Medical electronic and special integrated circuit design (IC) for biomedicine;
- Biomeasurements and identification of computer models of biomedical systems;
- Telemedicine and special tools for remote medical consultations.

At the Faculty of Materials Science and Ceramics (MS&C) investigations in Biomedical Engineering have been developed at three Departments: Department of Glass and Amorphous Coatings, the Department of Ceramics Technology and Fire-resistant Materials, and the Department of Biomaterials.

These investigations, involving bioceramics, bioglass, ceramic coatings for implants, carbon materials, polymers and composites, not only belong to the domain of basic or theoretical science, but also lead to the development of materials and techniques of great practical value. As an example, we can mention the investigation of calcium phosphate ceramics resulting in the registration of new implants for stomatology and bone surgery in the National Register of Materials and Pharmaceuticals. These implants have been introduced into production and on the national health care market. A number of carbon biomaterials developed at the MS&C Faculty have been positively verified in clinical trials in some medical institutions in Poland, and work is under way on the possibility of a more widespread use of these materials in bone surgery and regenerative medicine. Similarly, research on active inorganic bioglasses destined for application in bone surgery has been carried out.

It is the Department of Biomaterials, established at the beginning of 2003, that plays a leading role in the work involving Biomedical Engineering. Its main field of research is focused on the development of new materials, materials techniques and processes to be used in medicine. Investigations are also conducted on the production and assessment of mechanical, physical, chemical and biological properties of all groups of materials such as ceramics, metals and polymer composites.

The group of researchers currently investigating Biomedical Engineering problems at the ME&ICS Faculty is considerably smaller in number than the respective groups at the Faculties of EEACS&E and MS&C. Nevertheless, this group is responsible for various research projects on metallic biomaterials, which contribute to a better understanding of the correct cooperation of the implant material/tissue/bone/bodily fluids system. This cooperation has a major impact on the health and durability of implants. Investigations are also conducted on the outer surfaces of implants depending on the geometrical properties of surfaces such as corrugation and smoothness, and the defects of the surface layers of these materials. Investigations also involve energy stored in the form of defects in the crystal lattice structure, internal stresses in materials, surface tension, strengthening etc. from the point of view of the electrochemical thermodynamics of chemical reactions at the bone/tissue/implant/ bodily fluids boundary.

An important aspect of the studies conducted at the ME&ICS Faculty is the working time of safe use of implants in the body. This time is determined separately for each type of biomaterial taking into account its practical and functional properties. The working time of austenitic steel implants should not exceed two years, that of cobalt alloys and that of vanadium-titanium alloys should not be longer than 15 years and 20 years, respectively, whereas niobium-titanium alloys may be used for more than 20 years. It should be added that the high requirements imposed by medicine on implants make the currently produced biomaterials among the most expensive materials made by man.

The workers employed at the Faculty of Physics and Applied Computer Science (P&ACS) give strong support to MSBE and teach students of Biomedical Engineering. However, their main interests are focused on the development the Medical Physics specialty at their own Faculty. Nevertheless, the teaching of Medical Physics has very much in common (as regards the substance of the subjects taught rather than the organizational structure) with Biomedical Engineering education. It should be noted that MP education is focused on the use of ionization and non-ionization radiations such as ultrasound, microwaves, RF or optical radiation in medical diagnosis and therapy. Those working at P&ACS are also interested in the application of computer science in medicine, as well as in radiochemistry, radiopharmacology and nuclear medicine.

As mentioned earlier, the last Faculty cooperating with MSBE is that of Mechanical Engineering and Robotics (ME&R), where investigations focus on the design of rehabilitation equipment, medical remote controlled robots as well as special instruments used in the diagnosis of speech and hearing pathologies. The best example of these studies is afforded by a currently designed balance platform (a posturograph based on three servo-motors) which makes it possible to evaluate the shape of the trajectory of the patient's body by forced swaying of the base on which the patient is positioned. This platform will be employed in rehabilitation, otolaryngology, neurology, geriatrics and in the examination of pilots and athletes. The posturograph will make it possible to objectively assess patients with balance and mobility disorders on stable and non-stable bases with dynamic visual environment. Systematic studies are being planned on the effect of visual, atrial and somatosensoric stimuli on balance.

Another interesting feature of the studies conducted at the ME&R Faculty is also the application of EEG signals to control some mechanical devices, as well as the design and construction of a device to rehabilitate lower extremities and of a novel arm prosthesis. The most promising field of study at this Faculty, but also one that requires a large amount of money is that of designing and constructing specialized robots to be used in biomedicine. A new Polish surgical robot is potentially envisaged at the Faculty. This would be a great scientific success and may serve as the basis for creating laboratory workplaces for students.

Summary

Biomedical Engineering as a field of research and subject of university study has quite a long history.

Until the academic year 2005/2006, education in biomedical engineering was offered only as a specialization in other fields of studies, e.g. mechanics, automatics & robotics and electronics. The development of new technologies in medical diagnosis and therapy required a new approach to biomedical engineering education. Therefore, a consortium was set up of six technical universities (in alphabetical order): The AGH University of Science and Technology (Krakow), The Gdansk University of Technology (Gdansk), The Silesian University of Technology (Gliwice), The Technical University of Lodz (Lodz), The Warsaw University of Technology (Warsaw) and The Wroclaw University of Technology (Wroclaw). The consortium developed a new programme of education and then applied to the Ministry of Science and Higher Education for an official permit to create a new field of studies referred to as "Biomedical Engineering" (BME). In June 2006, the Ministry gave its consent to this proposal. The AGH University of Science and Technology was first in Poland to enroll students in BME in the academic year 2006-2007. In 2007-2008, all the members of the consortium had students in BME. In the academic year 2010-2011, BME education is being offered by 16 technical universities in Poland.

It has been noted that curricula taught at medical institutions of higher learning have been slowly and sometimes without firm resolution introducing elements involving Biomedical Engineering in their programs for educating physicians, dentists, medical rescuers and nurses. This situation is highly appreciated by all of those who for years have been making every effort to bridge a gap between medicine and technology, both in research and in teaching.

Taking all the above considerations into account it seemed worthwhile to describe the history of Biomedical Engineering education at the AGH University of Science and Technology in Krakow, which was the first in Poland to create proper conditions to establish multidisciplinary education in Biomedical Engineering. It was probably not without consequence that the author of the present paper held the position of Rector of AGH-UST at the critical moment biomedical engineering studies got off to a good start.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 21-28

TEACHING AND RESEARCH ACTIVITIES IN THE FIELD OF BIOMEDICAL ENGINEERING AT THE TECHNICAL UNIVERSITY OF LODZ

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Abstract: A teaching syllabus of a 3.5 year Bachelor of Science course on Biomedical Engineering and main research activities in the field of biomedical engineering that are carried out at the Technical University of Lodz (TUL) are described in the chapter. The teaching course, that was opened in 2007, is taught in English in the International Faculty of Engineering. The list of the offered subjects is outlined and those directly related to the field (i.e. 19 subjects) are discussed in more detail. More than 60% of the teaching hours of the course are devoted to tutorials and laboratories. Semester VI is the mobility semester during which the students leave for an Erasmus internship in EU country. The remaining part of the chapter covers main scientific specialties pursued at TUL, i.e. computed analysis of biomedical signals and images, laser therapy, systems aiding the disabled, biomaterials, implants, and radiation technologies in medicine.
Keywors: Biomedical engineering, biomedicine, biotechnology

Introduction

TechnicalUniversity of Lodz (TUL) has been carrying out research in interdisciplinary fields of medical electronics, biomaterials, radiation technology in medicine, biomechanics, surgical robots, implants, and laser therapy.Based on a long term interdisciplinary research record in these fields a 3.5 year Bachelor of Science course on Biomedical Engineering taught in English was opened in 2007.

The group of 25 students was enrolled and currently first graduates are completing this field of study. The study course consists of 7 semesters with 6th semester termed a mobility semester, during which our students participate in ERASMUS programme giving them an opportunity to elect and study subjects at foreign European universities. The complete Biomedical Engineering study programme offered at TUL is available online at http://www.ife.p.lodz.pl.

Preparation of the teaching materials (lecture notes and laboratory instructions) was financially supported by the EU Human Capital Programme.

This paper characterizes in more detail the Biomedical Engineering teaching syllabus adopted at TUL.Second part coversshortly main scientific specialties carried out at TUL that are closely related to the biomedical engineering field, i.e.:

- processing and analysis of biomedical signals and images,
- systems aiding persons with disabilities,
- biomaterials and implants,
- laser diagnostics and therapy,
- modeling of biochemical and biomechanical processes human body,
- applications of radiation technologies in medicine.

During preparation of the teaching program of the Biomedical Engineering course the specialists in the fields of electronics, telecommunications, nanotechnology, material science and biochemistry were involved. Currently, the following departments of the Technical University of Lodz deliver courses for the study programme:

- Faculty of Electrical, Electronic, Computer and Control Engineering
- Faculty of Mechanical Engineering
- Faculty of Chemistry
- Faculty of Biotechnology and Food Sciences
- Laser Diagnostic and Therapy Centre

in cooperation with the academic teachers from the Medical University of Lodz.

Programme

In the tables below the lists of subjects taught at each semester are presented.

The subjects, which cover the Biomedical Engineering specialtyare highlighted in bold letters. Detailed descriptions of these subjects are outlined in the next section.

SEMESTER I

	Course	Lecture	Tutorial / Laboratory	Total
1	Academic and Communication Skills I		30	30
2	Chemistry	15	45	60
3	Economics	30	15	45
4	Information Technology	15	30	45
5	Materials Science	15	30	45
6	Mathematics I	45	45	90
7	Measurements	30	15	45
8	Physics	30	20	50
9	Safety at Work and Ergonomy	10		10
		190	230	420

SEMESTER II

	Course	Lecture	Tutorial / Laboratory	Total
1	Academic and Communication Skills II		15	15
2	Basic Mechanical Engineering	40	50	90
3	Electronics and Electrical Engineering	40	50	90
4	Fundamentals of Programming	20	40	60
5	Foreign language		30	30
6	Management	30	15	45
7	Mathematics II	45	45	90
8	Modern Physics	20	20	40
9	Physical Education		30	30
		195	295	490

SEMESTER III

	Course	Lecture	Tutorial / Laboratory	Total
1	**Anatomy and Physiology**	30	30	60
2	**Biochemistry**	30	30	60
3	**Biophysics**	15	30	45
4	Business English for Engineers		45	45
5	**ComputerAided Design**	15	30	45
6	**Control Systems**	30	15	45
7	**Signal Processing**	30	30	60
8	Foreign Language		60	
9	Physical Education		15	
		150	285	435

SEMESTER IV

	Course	Lecture	Tutorial / Laboratory	Total
1	**Introduction to Medical Sciences**	15	15	30
2	**Image Processing and Computer Graphics**	30	30	60
3	**Sensors**	30	30	60
4	TeamBuilding and Communication Skills		45	45
5	Project		90	90
6	Foreign Language		60	60
7	Physical Education		15	15
		75	285	360

SEMESTER V

	Course	Lecture	Tutorial / Laboratory	Total
1	Medical Electronics	30	30	60
2	Biomaterials I	45	45	90
3	Biomechanical Engineering	30	30	60
4	**Implants and Artificial Organs**	30	30	60
5	MedicalInformatics	30		30
6	Robotics	15	15	30
7	Foreign Language		30	60
8	Physical Education		30	30
		180	210	390

SEMESTER VI

	Course	Lecture	Tutorial /Laboratory	Total
1	Mobility Semester			

SEMESTER VII

	Course	Lecture	Tutorial / Laboratory	Total
1	Biomaterials II	15	15	30
2	Final Project		10	25
3	Final Project Seminar		15 (seminar)	15
4	Industrial Placement			
5	Intellectual Property Protection		15 (seminar)	15
6	Law & Ethics in Biomedical Engineering	30		30
7	Medicall maging	30	45	75
8	Microsystems in Medical Applications	30	15	45
		105	115	220

Subject descriptions

Below, an overview of the learning outcomes and teaching programmes for the offered courses are given.

Biophysics

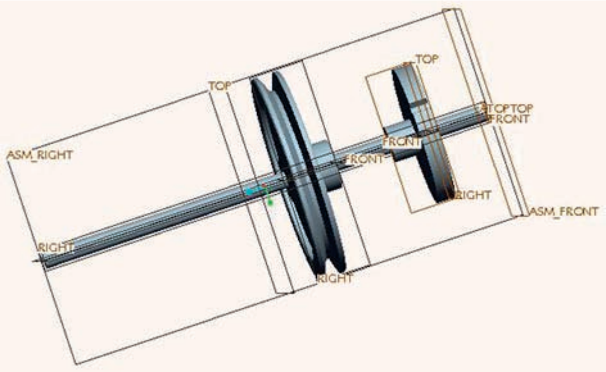
After completing the course a student is equipped with a basic knowledge in biophysics. He is familiar with thermodynamics of open systems, molecular constituents of living organisms, mechanisms of feedback and molecular transport through biological membranes, blood flow and muscle contraction, effects of physical fields, senses and their functions and kinetics of biochemical reactions.

Biochemistry

A student will acquire skills in understanding structure, properties and biological role of fundamental biomolecules such as amino acids, proteins, carbohydrates, nucleic acids and lipids. He can point out properties and classify enzymes, understand kinetics of enzyme-catalyzed reactions and fundamentals of enzymatic analysis applicable to medicine. He will have general knowledge about metabolism and principal metabolic pathways.

Computer Aided Design

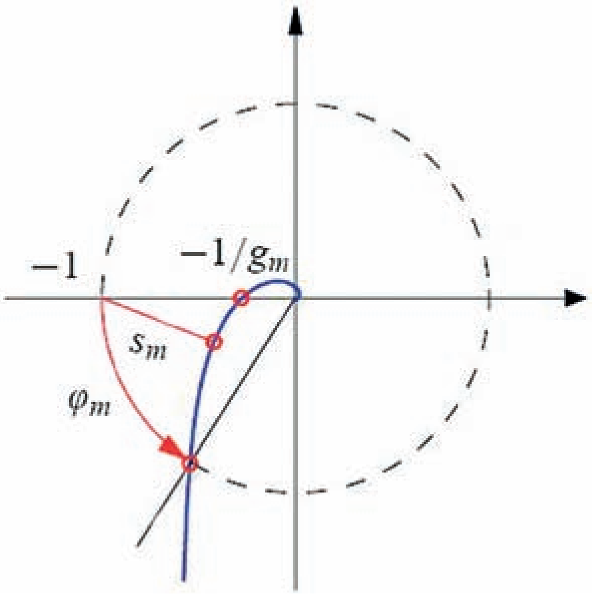
The subject allows students to extend the knowledge and practical use of CAD/CAM/CAE systems. The student will be able to apply 3D modelling techniques as well as methods of multi-variant part design and their assemblies. The students will also know how to automatethe technical documentation and apply computer techniques in engineering calculations.



Control Systems

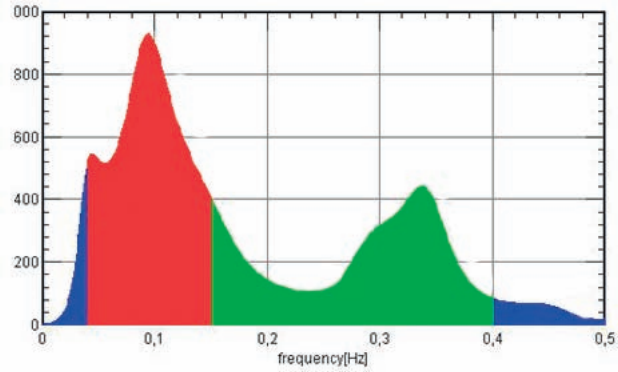
There are four outcomes to this unit. A student will be able to:

– Apply mathematical modelling to dynamic systems,
– Analyse responses of control systems,
– Understand feedback control systems,
– Design linear time invariant control systems with corrective action.



Signal Processing

Having completed the course, students will be able to apply the methods of signal acquisition, analog and digital processing, use of analysis and recognition techniques for aiding medicial diagnoses with the use of features extracted from biomedical signals.



Anatomy And Physiology

Having completed the course, students will be able to recognize the anatomical features of body systems and their relationships to one another; Explain the functioning of the body's structural machinery; Locate anatomical features on models and lab specimens; Apply knowledge of body systems to disease conditions.

The student will also have an opportunity to: engage in challenging learning experiences which offer them an opportunity to explore varied responses to the human condition, develop a greater sense of maintaining personal health.

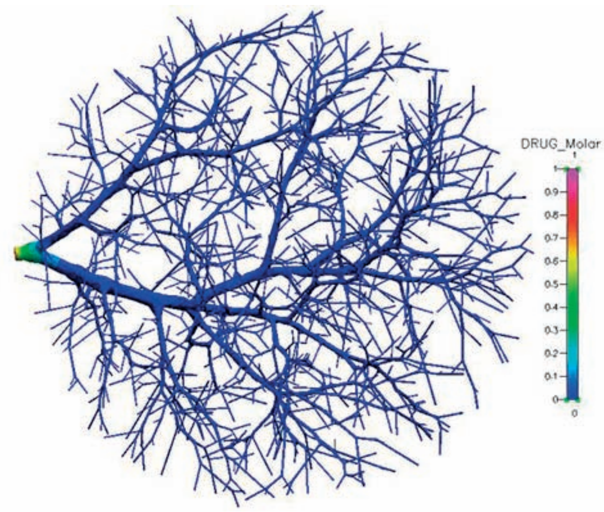
Introduction to Medical Science

Having completed the course, students will be able to:

Get to know about causes and sorts of common medical intervention using in pathology conditions; Have some necessary knowledge dealing with the functioning of the body; how parts work and carry out their life-sustaining activities; Recognize how structure and function are interrelated in the body; Point illnesses risk factors; Apply knowledge of body systems to disease conditions; Understand health service in Poland.

Image Processing and Computer Graphics

After completing the course a student will be able to:
- preprocess images to highlight their predefined features,
- apply image compression techniques,
- use segmentation techniques for different image types (tomographic, ultrasound etc),
- design image analysis procedures and apply classifcation techniques for aiding medical diagnoses,
- understand and use in practice computer graphics techniques and tools.



Sensors

Students are provided with general information on chemical sensing and molecular recognition. Special attention is focused onunderstanding of the optically active sensing systems(molecular and polymeric) and to optical analytical methods.

Biomechanical Engineering

After completing the course students will be able to model and design biomechanical elements and systems taking into account mechanical and physical properties of human bones and joint structures, parameters of body posture and endurance of tissue materials.

Biomaterials I

Students will know types of materials used for construction of medical devices and implants; understand biomaterials structure and properties; methods of attestation and technical acceptance of biomaterials.

Implants and Artificial Organs

Students will know how to select proper materials for manufacturing of the fibrous implants, design of the structure and resulting properties of the implants. They will also acquire skills in quality evaluation of the implants.

Medical Electronics

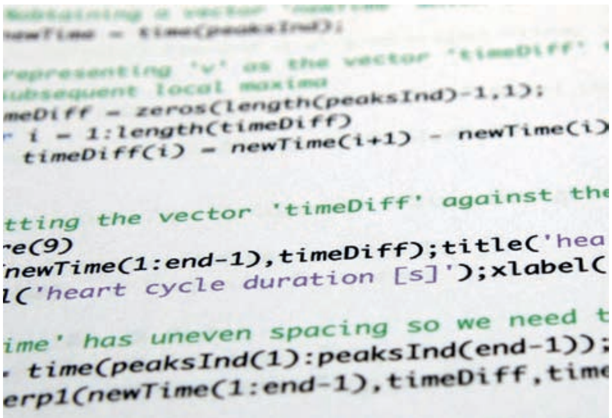
Students will be able to apply measurement methods in medical diagnosis techniques, will know how to approach the problem of designing medical equipment and measurement systems including EKG, EOG,EMG, EEG, blood pressure and temperature recorder as well as advanced sensors like spirometer,pulsoxymeter and Doppler flow meter.

Medical Informatics

After completing the course, a student is able to design simple algorithms for medical applications and to carry out the basic operations on multidimensional biomedical data databases.

Robotics

After completing the course, a student is equipped with a basic knowledge in robotics. He is familiar with manipulator kinematics, manipulator dynamics, trajectory planning, and control of robots. He knows methods and languages for robot programming.

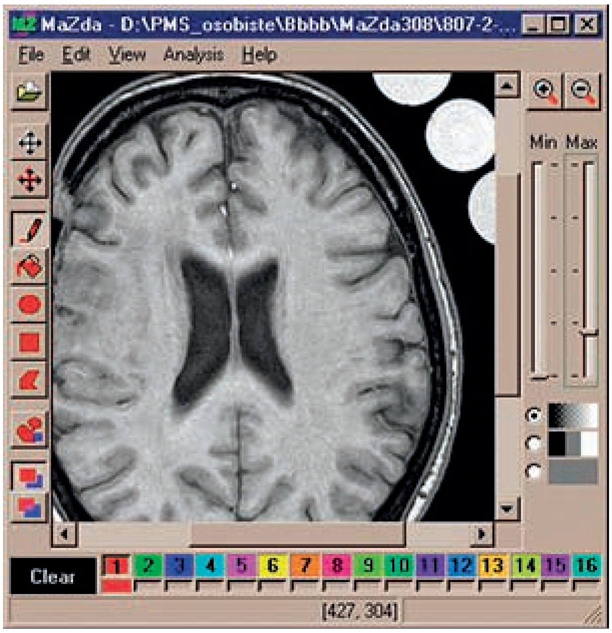


Biomaterials 2

Students are able to select proper materials for manufacturing of the fibrous medical devices, designthe structure and resulting properties of the medical devices. They gainskills in quality evaluation of thefibrous biomaterials.

Law and Ethics in Biomedical Engineering

Students acquire knowledge and understanding of law regulations and ethical principles in medicine and biomedical engineering

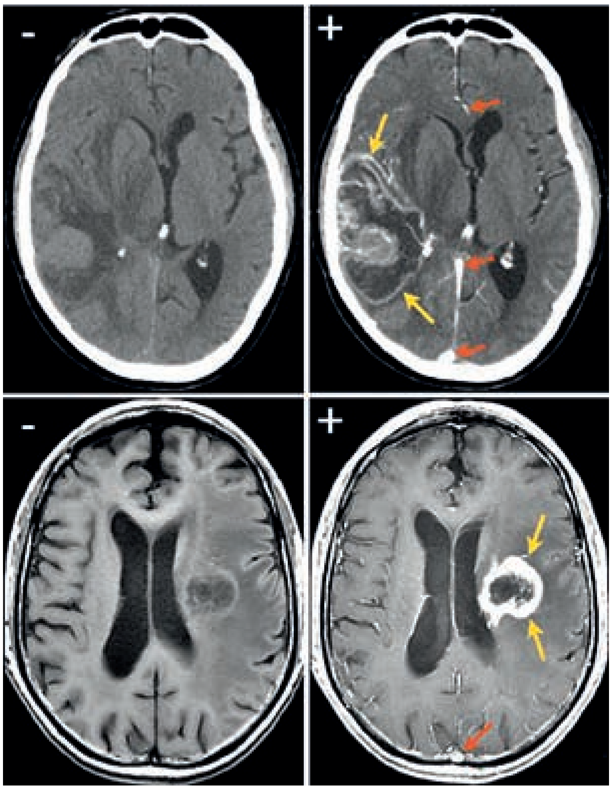


Microsystems in Medical Applications

Students will be able to apply in practice design methods of microsystems and micromachining technologies. They will understand physical phenomena used in microsystems and principle of operation and implementation of microsystems. The will gain abilities in modelling of basic components of microsystems.

Medical Imaging

Students will understand basic medical imaging methods including endoscopy, imaging based on ionizing radiation, analog and digital plane imaging, radioscopy, computed tomography, nuclear medicine imaging etc. along with their application in medical diagnosis.



Research activities in the Technical University of Lodz

The Technical University of Lodz since many years has carried out numerous research activities in the wide field of biomedical engineering. The most important achievements cover:

- establishment of the Laser Diagnostics and Therapy Centre (1994) aimed at analysis of the effect of laser light on human body and implementing new methods of treatment with the use of laser techniques [1].
- development of software and computer systems for analysis of biomedical signals and images, performed at the Medical Electronics Division, Institute of Electronics [2]. This includes Mazda software for quantitative analysis of image texture [3].

– development of thermographic systems, acquisition and analysis of medical thermograms (e.g. breast cancer images, blood clot images in deep vein thrombosis) at the Institute of Electronics and the Department of Microelectronics and Computer Science. [4], [5].
– implementation of electronic systems aiding the communication and travel of the visually and physically impaired (Institute of Electronics) [6].
– synthesis and characterization of polymeric hydrogels with a number of biomedical applications, such as wound care products or dental and ophthalmic materials (Institute of Applied Radiation Chemistry) [7].
– synthesis of nanocrystalline diamond (NCD) with many medical applications, e.g. medical implants coated with NCD (Endoprothesis of a hip joint, orthopedic screws), Institute of Materials Science and Engineering [8].

– design and development of modules for medical robot (Department of Robots and Automation) [9,10].
– modeling of blood vessel stents, research on biomechanics of brain, heart, skeleton (Department of Automation and Biomechanics) [11, 12].
– development of the type series of single disk artificial heart valves for pediatric ventricular assist devices to design and manufacture one-disk valves (The Institute of Turbomachinery) [13].

Conclusions

Biomedical engineering is the field of study that combines three main disciplines: biology, medicine and engineering. Students must acquire versatile skills to meet diverse technological challenges of the future. While preparing the course we were convinced the students should get both solid background knowledge in mathematics, biochemistry and biophysics that can be used in such applied fields like information and communication technology (ICT), telemedicine, material science, signal and image diagnosis, nanotechnology, robotics and artificial organs.

A biomedical engineer must be prepared to work in various environments: research and development centers, industry, engineering and clinical units. His expertise will probably become outdated with each decade, hence life-long learning approach is a key factor in a successful professional career in biomedical engineering field.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 29-34

NEUROINFORMATICS

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Abstract: This article describes the world's first BSc course in Neuroinformatics, launched in 2009 at the Faculty of Physics, University of Warsaw. The curriculum includes solid background in physics, mathematics, informatics, statistics and signal processing, and parallel biomedical course from basics of biochemistry, biology and histology, to bioelectricity and neurobiology. Over 300 hours of biosignals laboratories are run entirely on GPL (open source) software, which students are free to explore, modify and use at no charge in future businesses including e.g. neurofeedback, brain-computer interfaces or eyetracking applications. Project of a matching MSc course has been submitted to the Ministry.
Keuwords: Neuroinformatics, EEG, Free Software, Neuroscience, Brain-Computer Interface, Eyetracker

Introduction

Neuroinformatics

Neuroinformatics can be defined as the application to the neurosciences of methods for measurement, analysis and modeling derived from the physical sciences. It integrates information across all levels and scales of neuroscience–from genes to behavior–to help understand the brain and treat disease. It encompasses the tools and techniques for data acquisition, sharing, publishing, storage, analysis, visualization, modeling and simulation. A tremendous amount of remarkably diverse data about the brain is produced and published by the neuroscience community every year and this is growing at an exponential rate. Neuroinformatics provides new techniques for managing and analyzing the data to make data sharing and reuse more efficient.

Integrating research findings from different labs and multiple experimental techniques is critical to understand the complex details of neural structure and brain function. Neuroinformatics methods facilitate new insights through the integration and analysis of large, diverse and multi-faceted data sets. Establishment of links between studies on all levels of detail promotes new scientific insights, makes already existing data more valuable, and new studies more reliable.

International Neuroinformatics Coordination Facility (INCF)

International Neuroinformatics Coordination Facility (INCF, http://incf.org), established in 2005, is an international organization devoted to advancing the field of neuroinformatics. Currently, the INCF Community consists of 16 member countries and associated research groups, consortia, funding agencies and publishers in the field. A significant part of its efforts is directed at training – c.f. a quote from http://incf.org/about/what-we-do:

Neuroinformatics poses a specific challenge for training, as this variety of knowledge and research cultures is only rarely combined in one single place and often falls between traditional academic departments. The mission of the recently formed Training Committee is to plan, evaluate, validate and decide on training-related issues within INCF.

Neuroinformatics training

Neuroinformatics, the new research field situated at the intersection of neuroscience and the physical sciences, is by its nature interdisciplinary. It requires the integration of knowledge from mathematics, physics, computer science and engineering together with detailed knowledge of the nervous system. It is essential that neuroinformaticians should be able to communicate with researchers across the spectrum of all relevant disciplines. Neuroinformatics poses a specific challenge for training, as this variety of knowledge and research cultures is only rarely combined in one single place and often falls at the boundaries of traditional academic departments [1].

Report of the 1st INCF Workshop on Needs for Training in Neuroinformatics held in 2008 [1] indicates also the potential problems:

(...) It is difficult to train students so that by the end of their first degree they are equipped to do neuroinformatics research,

having acquired sufficient knowledge of neurobiology coupled with the requisite mathematical and computational skills. To attain this solely through an undergraduate degree programme requires several structural and social barriers to be overcome.(...)

The next chapter describes overcoming these barriers in Warsaw. Later in the document we read:

Currently there is no undergraduate programme in neuroinformatics. There is a BSc course under development and due to be launched at Warsaw in Autumn 2009. Half of the curriculum is made up of courses in physics and applied mathematics. In the other half there are (i) courses in cell biology, neurobiology and psychology together with (ii) a variety of elective courses including neural networks, statistical inference and programming. In addition, there is (iii) significant practical training in EEG acquisition and analysis.

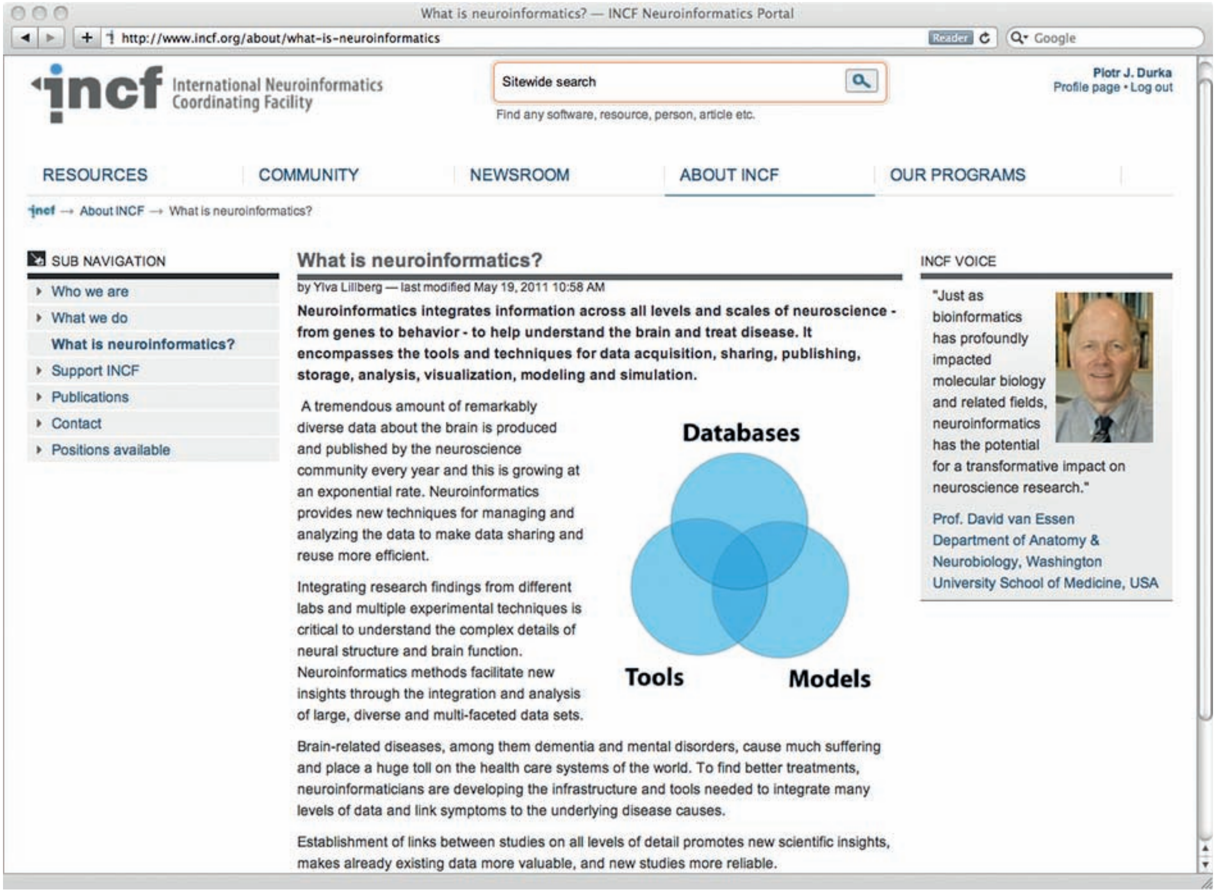

Fig. 1. http://incf.org, website of the International Neuroinformatics Coordination Facility

Launch of the world's first Neuroinformatics BSc

Slightly before the above mentioned 1st INCF Workshop on Needs for Training in Neuroinformatics [1], preparations for launching new interdisciplinary directions of studies started at the University of Warsaw. Apart from that, two more facts contributed to the favorable situation, which allowed us to launch the world's first Neuroinformatics BSc:

1. Research and teaching at the Department of Biomedical Physics, related to the modeling and analysis of the electrical activity of the brain
2. My participation in the works of the INCF training committee [2]

In the following chapter we elaborate on the first point.

Local background

Tradition of biomedical teaching at the University of Warsaw dates back to 1974, when the Poland's first MSc specialization in Medical Physics was started at the Laboratory of Medical Physics (currently Department of Biomedical Physics) of the Faculty of Physics. Over the years, scientific interest of the staff drifted from the radiation physics to the application of physical methodology in neurosciences, which included modeling of brains electrical activity and novel methods for EEG signal analysis. Due to the increasing demand for specialists in these fields, graduates of Medical Physics started to receive double education in partly diverging fields of medical physics and neuroinformatics, although the latter term at that time was not established yet. When the Faculty started preparations for a new interdisciplinary direction of studies, it came up as a natural idea to separate these two directions, which still allowed for maintaining part of lectures delivered by the Department's staff as common to these two specializations.

Detailed program of the Neuroinformatics BSc is presented in Table 1. It was based on the following observations:

– Many neuroinformaticians and computational neuroscientists have physics as the primary higher education background (BSc/MSc).
– A strong background in applied mathematics and the physical sciences is definitely an advantage for these fields.
– Physicists working in neuroscience lack solid biomedical foundations, which would stem from basic and well ordered designed knowledge of (bio)chemistry, biology and physiology.
– The European Bologna Process suggests that 3-years BSc studies should not only provide foundations for the MSc course, but also give self-contained knowledge.

As a result, the 3-years BSc program for Neuroinformatics at the University of Warsaw includes, in semesters I—IV, 360 hours of basic math (Algebra + Analysis), 270 hours of basic physics and 180 hours of physics laboratories. These lectures are adopted from the BSc program in physics, slightly modified in some cases. At the same time, from semester I, a slightly leaner biomedical course is started in parallel: basics of chemistry with elements of biochemistry, biology of the cell, histology, bioethics, bioelectricity, psychological aspects of contacts with a patient and first aid, neurobiology. Each of the above topics accounts for 30 hours. Yet still there is a space for specialized topics like Statistical Inference, Signal Processing, IT, Database Technology, Computer Programming and Artificial Neural Networks. Finally, a large part of semester V and VI are devoted to practical training in EEG acquisition and analysis, including neurofeedback and brain-computer interfaces. Syllabi in Polish and English are available from http://neuroinformatyka.pl.

This curriculum gives solid foundations for future MSc studies, planned in the direction of modeling. Nevertheless, already this education makes a BSc graduate a valuable member of an interdisciplinary research team, even if only owing to informatics, statistical and signal processing skills, combined with basic understanding of biomedical issues, which allow for efficient communication with people outside the hard sciences.

Implementation

After adjustments for the requirements of Polish law and the European Bologna Process, the application for a new interdisciplinary undergraduate program "Applications of physics in biology and medicine" has been accepted by the Ministry of Education. This application was necessary, because the criteria for educating a physicist require so many hours of "pure" physics and mathematics, that basically no space is left for the biomedical part in any of the five new specializations planned within this program. Neuroinformatics was one of the five new specializations, listed explicitly in chapter "Funding".

Implementing the course required preparation of completely new lectures and classes, as well as setting up a new laboratory of biosignals analysis. These issues were surely among the barriers mentioned in [1] (section "Neuroinformatics training"), but such a start-from-the-scratch approach offers also tremendous opportunities for introducing changes and new ideas, which otherwise would be very difficult to embed in ongoing courses. In this case, we used this opportunity to introduce the following novel principles and elements:

1. teaching informatics from the very beginning is based on a modern object-oriented programming language Python, gaining increasing significance in the neuroscience and neuroinformatics community,
2. teaching the most advanced topics like implementation of brain-computer interfaces and cheap eyetrackers,
3. owing to the support mentioned in the chapter "Funding", lecturers and assistants are required to prepare complete teaching materials at http://brain.fuw.edu.pl/edu
4. finally, all the laboratories are based entirely on Open Source software (mostly GPL).

Free Software

The last decisions mentioned in the previous chapter gives several immediate advantages for both education and using the acquired knowledge in practice:

1. Students have freedom to use at home exactly the same software as in classes, without bothering about the licenses. In case of specialized signal processing packages, the cost of a single license usually starts between 10^3 and 10^4 Euro.
2. Students can play with the source code, and in future modify the software for particular business or research needs.
3. Upon finishing the BSc, graduates have expertise and experience with the software packages which they can start using for any purpose including commercial at no charge.
4. Owing to the availability of high-level libraries, Python is viewed as a possible free replacement for the commercial package Matlab, also widely used in neuroinformatics especially for larger projects, which also favors the graduates in many employment opportunities.

Switching from Matlab to Python was a decision based upon careful observation of the trends in neuroinformatics, development of the major projects and discussions with involved scientists. But for the remaining points 1.– 3. a decision would not be enough without the appropriate free software. Fortunately, about that time the two major software projects of the Department of Biomedical Physics started reaching a stable and mature stage. These were Svarog and OpenBCI.

SVAROG (http://svarog.pl) stands for Signal Viewer, Analyzer and Recorder On GPL. It was first started as the flagship implementation of the SignalML language for metadescription of biomedical time series (http://signalml.org), which is a solution that we proposed for the problem of incompatibility of different binary formats of biomedical time series. Over the years it became the only free software offering the interface for visualization of biomedical time series – a step of tremendous importance in dealing with signals like EEG – offering functionality on the level of the commercial packages. It also features an open API which allows connecting advanced signal processing methods to an intuitive interface, thus making them available to the target

Fig. 2.
Setting up EEG recording at one of the first classes at the new Neuroinformatics Lab.

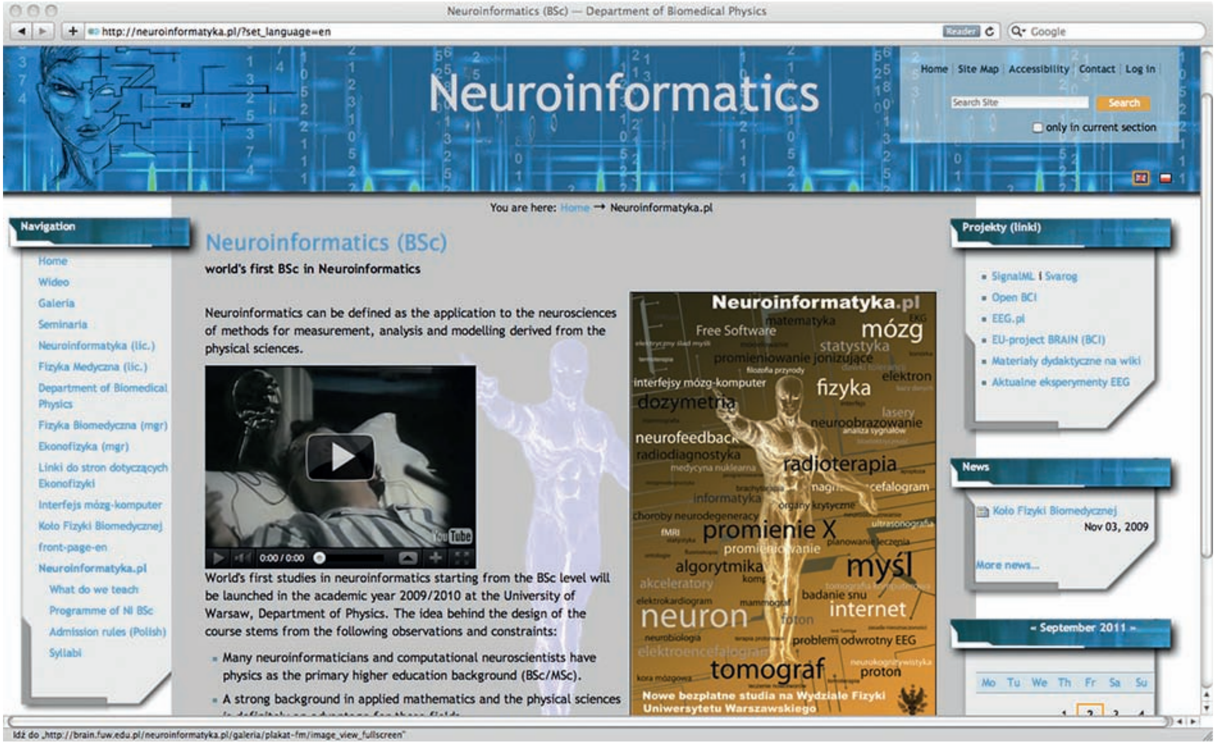

Fig. 3.
Website http://neuroinformatyka.pl, containing the program and syllabi of the Neuroinformatics BSc course.

audience of clinicians, neurologists and psychologists rather than just engineers. Finally, the "R" for recording was achieved via the second project.

OpenBCI (http://openbci.pl) was started in 2008 as an MSc project of two students of the Faculty of Mathematics, Informatics and Mechanics, interested in interdisciplinary research in my lab. The system provided foundations for a basic framework for construction of a brain-computer interface (BCI). Most BCIs require online processing of the electroencephalographic (EEG) data, therefore drivers for EEG amplifiers were present from the beginning. As the module for viewing the EEG we used Svarog, which started the happy marriage of these two packages. Nowadays, depending on the application, one can say that Svarog is just a signal viewer for OpenBCI, or the OpenBCI serves just as a device driver for Svarog. In any case, these two packages together comprise probably world's first open system for EEG recording and online processing, offering functionality matching the commercial packages. Svarog is written in Java, which provides convenient multiplatform graphical interface. OpenBCI is mostly Python, which allows for simple modification and creation of new usage scenarios.

Funding

The project *Physcis facing challenges of XXI century* (http://fizykaxxi.fuw.edu.pl/) is funded in part by the EU under the *Human Capital Operational Programme 2007–2013, Priority axis IV. Tertiary education and science, measure 4.1 strengthening and development of didactic potential of universities and increasing the number of graduates from faculties of key importance for knowledge-based economy, sub-measure 4.1.1 Strengthening and development of didactic potential of universities.* The project concerned the five new specialization courses included in the "Applications of physics in biology and medicine" program:

1. Molecular biophysics
2. Molecular designing and bioinformatics
3. Medical physics
4. Neuroinformatics
5. Optometry

Among the targets of this funding was the preparation of new courses. I forced through an interpretation where "preparation" means not only the first, one-time delivery of a course, but also creation of complete course materials available on the Web, hence also free of copyright and IP issues. Sustainability is achieved by the wikimedia infrastructure, where subsequent lecturers will be taking over and updating the material. This started the growing collection of teaching materials in Polish at http://brain.fuw.edu.pl/edu. We hope to continue this project also for the coming MSc studies in neuroinformatics.

First Experience

There has been two years now since the Neuroinformatics course has been offered to the students. Despite of many problems that had to be solved and still existing difficulties, the overall experience so far is very encouraging.

First of all, there are many candidates. This proves efficiency of a non-standard marketing model where the promotion of the totally new word "neuroinformatics" was based mostly on the public appearances of the members of the team, frequently interviewed in TV, radio and press in relation to starting the first Polish experiments with brain-computer interfaces. As a result, in spite of the relatively small financial investments in promotion of the new discipline, in the first edition the number of candidates exceeded the number of planned places fivefold. In the second edition, this number raised to seven, which can be referred to the actual quality of teaching and opinions, which students of the first edition shared with potential candidates.

From the teacher's perspective, the students of this specialization are surprisingly well motivated. Some of them have had significant problems with the physics and mathematics in the first 4 semesters – these courses are taught on the same difficulty level as for the students of Physics, but squeezed in a smaller amount of hours. Students with different backgrounds (mathematical vs. biochemical or even social sciences) were helping each other, since also some of the biochemical classes were challenging to the mathematically oriented ones.

Mentioned above free software, used at the laboratories, was not flawless–honestly it should be termed beta at this stage. Therefore, students came across many problems during the courses, but they regarded it more like a challenge than annoyance to fix the problem themselves, taking the positive approach of learning more this way.

Overall, together with a huge organizational burden that we shared with the Faculty, these studies still pose for us a constant challenge – programs of many of the classes have to be adjusted after the first experiences, and we are working on the MSc course (this effort is coordinated by dr hab. Piotr Suffczyński). Overall, we consider this great experience a success. Fortunately, this opinion seems to be shared by the students.

Summary

This paper describes the circumstances that led to the creation of the world's first Neuroinformatics BSc program at the University of Warsaw, and the unique features of these studies, like the free availability of teaching materials at http://brain.fuw.edu.pl/edu, practical classes with brain-computer interfaces and eyetrackers based entirely on Free Software (http://openbci.pl) and incorporation of the trends in neuroinformatics as envisaged by the INCF Training Committee [2]. Further details, including the syllabi of the courses, are available from http://neuroinformatyka.pl –depending on the language settings, also in English.

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2. INCF Training Committee, http://incf.org/programs/training-committee.

semester I	Lect	Lab/Ex	ECTS	
Mathematics I	60	120	14	exam
Physics I	45	45	8	exam
Information Technology	30	45	6	exam
Basics of chemistry with elements of biochemistry	30		2	exam
Health and safety, lab ergonomy			0,5	credit with grade
Intellectual property basics			0,5	credit with grade
Physical education	30			credit
semester II				
Mathematics II	90	90	14	exam
Physics II	45	30	6	exam
Investigation of the uncertainty of measurements and preliminary laboratory	20	40	5	credit with grade
Statistical inference	30	30	5	exam
Physical education	30			credit
semester III				
Physics III	45	30	6	exam
Fundamentals of quantum physics and the structure of matter with elements of thermodynamics	30	30	6	exam
Laboratory on measurement techniques and foundations of physics	15	45	5	credit with grade
Biology of the cell	30		2,5	exam
Signal analysis	30	30	6	exam
Histology	15	15	2,5	exam
English	60		2	credit with grade
Physical education	30			credit
semester IV				
Physics and electronics laboratory	15	45	5	credit with grade
Bioethics for biologists	30		2,5	credit with grade
Basics of human anatomy and physiology	15	15	2,5	exam
Programming for neuroinformaticians		90	8	credit with grade
Bioelectrical signals laboratory		60	6	credit with grade
Bioelectrical signals	15		2	exam
English	60		2	credit with grade
Physical education	30			credit
English certification exam			2	exam
semester V				
Medical imaging	60		6	exam
Intellectual property and personal data protection	30		2	credit with grade
Basics of scientific presentations	30		2	credit with grade
Psychology of contacts with the patient and first aid	30		2	credit with grade
Introduction to database technology	15	45	4	credit with grade
EEG laboratory I		150	14	credit with grade
semester VI				
EEG laboratory II		120	10	credit with grade
Neurobiology	30		2,5	exam
Artificial neural networks	25	25	3,5	exam
Apprenticeships		60	4	credit with grade
BSc laboratory		90	10	credit with grade

Tab. 1. Programme of the Informatics BSc at the Faculty of Physics, University of Warsaw, source: http://brain.fuw.edu.pl/neuroinformatyka.pl/programme-of-bsc-polish?set_language=en. Syllabi of these lecture are available in English at http://brain.fuw.edu.pl/neuroinformatyka.pl/sylabi

BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 35-46

SILESIAN UNIVERSITY OF TECHNOLOGY FACULTY OF BIOMEDICAL ENGINEERING – WIDE OFFER FOR FUTURE BIOMEDICAL ENGINEERS

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Abstract: The Biomedical Engineering appeared as an academic discipline at Polish universities five years ago. Since that time, many young people have chosen it as their future profession. A few hundreds have already received the engineer degree. Most of them decided to continue their education to become Master of Science in Biomedical Engineering. The Silesian University of Technology has been providing courses in Biomedical Engineering since 2007. Currently, on each of the four years of studies 60-100 students participate in various available courses. The education process started at the Faculty of Automatic Control, Electronics and Computer Science, and now continues within the new Faculty of Biomedical Engineering, the first and only in Poland at the moment. Knowledgeable and experienced professors, wide spectrum of cooperating medical, industrial and academical units and freshly equipped labs allow to provide the offer of modern studies in a challenging and interdisciplinary domain. The paper presents various aspects of biomedical engineering as it was in past and as it is today. A brief presentation of its history, educational offer, cooperating entities and infrastructural facilities as well as a summary of experiences after four years of studies and a short review of the research are included.
Keywords: biomedical engineering, educational offer, undergraduate studies, postgraduate studies, Ph.D. Studies, Gliwice, Silesia

Introduction

Biomedical engineering as an academic discipline is rapidly emerging in Poland. Since its appearance at Polish universities five years ago, it has been chosen by many students interested in medical applications of informatics, electronics, mechanics, material sciences and automation. Just now, the first adepts of biomedical engineering are starting to practically apply their freshly obtained skills for the benefit of patients and physicians.

It is not a common knowledge, however, that various aspects of biomedical engineering has long been available in many Polish research centres. At the Silesian University of Technology the first initiatives go as far back as to 1969, when the department of Electronic Medical Equipment was established. In the following years many contributions to the medical field have been made by various divisions and individual scientists in cooperation with local medical institutions, universities and health centres. A major progress was observed during years 1993-1999 when the Centre of Biomedical Engineering was established within the Silesian University of Technology in order to permit various organizations to cooperate and research.

An initiative that led to the first biomedical engineering specialization within the Faculty of Automatic Control, Electronics and Information Technologies has thus been welcomed by both scientists and students, especially, that Ph.D. studies had been started a few years ago. Constant interest in new technologies led shortly after to the first Faculty of Biomedical Engineering in Poland, where both under- and postgraduate studies possibilities are available for students.

Within the Biomedical Engineering Faculty, during undergraduate studies, two major specializations are available: Medical Informatics and Equipment and Medical Products Engineering. Even more options are available for postgraduate students: Informatics in Medicine, Biomechanics and Medical Equipment, Engineering of Implants, Hospital and Rehabilitation Equipment, Electronic Medical Equipment and Sensors and Biomedical Information Processing.

Research and educational activities are led in new Faculty's laboratories including advanced equipment for medical imaging and visualization, biomechanics and biomaterials.

Cooperation between the faculty, major health, business and academic centres, such as: Medical University of Silesia, Radiological laboratories, Upper Silesian Rehabilitation Centre, Foundation for Cardiac Surgery Development in Zabrze or ITAM Institute of Medical Technology and Equipment permit constant evaluation of educational plans.

A Bit of History

Biomedical engineering integrates various technical fields to support medicine and healthcare projects. Materials and mechanics knowledge is necessary to create implants or dentures. Information technologies permit faster medical information processing and computerized diagnosis and therapy systems to emerge. Automation and electronics are needed in the process of medical equipment construction. All these have long been available at the Silesian University of Technology, especially at the Faculty of Automatic Control, Electronics and Information Technologies (formerly Faculty of Automation), Faculty of Mechanical Engineering and Centre of Biomedical Engineering and are now continued within the new Faculty of Biomedical Engineering.

Faculty of Automatic Control, Electronics and Information Technologies

Most of the faculties of the Silesian University of Technology are located in the centre of the Upper Silesian Industrial Region, where a number of cities create an urban agglomeration with current population of over 2 million people. In this relatively small area, a medical university with many specialized hospitals, a few major health centres and many local hospitals are located nearby forming a large medical base. A number of companies constantly work to provide equipment, materials, service and know-how for emerging and existing health centres.

A similar situation, albeit in a smaller scale, has been observed during the late 60s of the 20th century. Like today, engineers were needed to maintain, improve and develop specialized medical systems. This demand has been recognized by the members of Faculty of Automation and later found support of the authorities of the Silesian University of Technology. Electronic Medical Equipment department was established (Fig. 1). Two years later Medical Automation and Equipment Institute was formed within the Faculty of Automation. Cooperation was started with the Silesian Medical University and Institute of Medical Technology and Equipment. For many years engineers and masters of science have been educated in the interdisciplinary field of medicine, automation and rapidly emerging electronics and computer sciences. This tradition has been continued despite organizational changes within the Faculty and the University – first by the Institute of Medical Equipment and Automation in Medicine, then by the Division of Biomedical Electronics. In the meantime Ph.D. education in Biomedical Engineering has started.

Fig. 1. Electronic medical equipment department – research work.

These years of experience permitted the creation of a biomedical engineering discipline as soon as it had been approved by the Polish government. Strong cooperation has been established with the Faculty of Mechanical Engineering and the Centre of Biomedical Engineering that finally led to the foundation of the new Faculty of Biomedical Engineering in 2010. Staff of the Faculty is heavily represented in new departments of Informatics and Medical Equipment as well as Biosensors and Biomedical Signals Processing.

Faculty of Mechanical Engineering

At the Silesian University of Technology, the Faculty of Automatic Control, Electronics and Information Technologies was not the only one actively involved in the research on medical technologies. Strong demands regarding new medical materials for implants as well as surgery instrumentation, prostheses, rehabilitation devices and many others stimulated research projects and activities within the Faculty of Mechanical Engineering. By the initiative of the faculty's staff, already in mid-90's the specialization of Biomechanics and Medical Equipment was opened. Also by initiative of the faculty's staff the Centre of Biomedical Engineering was founded for broad cooperation of various biomedical engineering entities.

Within the faculty, biomedical engineering research has been actively conducted especially within the institutes of Engineering and Biomedical Materials and Department of Applied Mechanics. Emphasis has been put on both development and analysis of biomaterials and practical application of mechanical knowledge in providing better solutions for medicine. During research, new methods for designing, construction and evaluation of implants have been proposed. Optimization techniques have been introduced into the development of biomaterials. Novel methods for bone fracture therapy have been proposed.

Faculty has been actively cooperating with medical manufacturers and suppliers in the biological evaluation of medical devices in preclinical and clinical conditions and research on a new generation of controlled rehabilitation equipment (design, production, technical and clinical tests) etc.

Staff of the Faculty initiated the foundation of Centre of Biomedical Engineering and is now heavily represented in new departments of Biomaterials and Medical Devices Engineering as well as Biomechatronics**.**

Centre of Biomedical Engineering

Silesian University of Technology is not the only biomedical engineering research centre available in this part of Poland. In Upper Silesia, for a number of years issues of biomedical engineering have also been investigated in Medical University of Silesia and University of Silesia. During the years, numerous scientific and educational problems of interdisciplinary nature have been solved on the basis of mutual contacts and cooperation of different research teams within the internal units of these universities.

Efforts towards establishing an organizational unit coordinating the cooperation of scientific-research and teaching groups were finished in 1999. An agreement has been signed by rectors of three universities and the first in Poland inter-university Biomedical Engineering Centre has been established.

The Centre unites research and teaching groups and coordinates their interdisciplinary scientific, education and training activities in the field of biomedical engineering. It fulfils its goals by cooperation with specialists employed in internal units of the individual universities as well as various scientific and industrial laboratories.

Staff of the Biomedical Engineering Centre is actively involved in both research and organizational activities of the new faculty of Biomedical Engineering.

Biomedical Engineering in the Silesian University of Technology

During past two years education of Biomedical Engineering at the Silesian University of Technology, initially led by the Faculty of Automatic Control, Electronics and Information Technologies in cooperation with the Faculty of Materials Engineering and Metallurgy, has been systematically taken over by the new Faculty of Biomedical Engineering. The continuity is being maintained, however, and the profiles of adepts of both new and old study programmes are similar.

Currently, both undergraduate and postgraduate studies are available only at the Faculty of Biomedical Engineering. Ph.D. studies are still conducted at the Faculty of Automatic Control, Electronics and Information Technologies.

The teaching system implemented at the Silesian University of Technology fulfils the requirements of the European Bologna Process.

Undergraduate Studies

Undergraduate Biomedical Engineering studies carried at the Silesian University of Technology are available in two different specializations: Medical Informatics and Equipment and Medical Products Engineering. Each year circa 120 students start their education with basic technical and biomedical courses: mathematics, programming, science, chemistry, as well as anatomy, biochemistry, biomaterials, basics of medical imaging, artificial organs, medical equipment etc. At the beginning of the 4th semester specialistic courses are chosen, different for each specialization. Throughout last two semesters (6th and 7th) a graduation project is developed using the obtained skills. Education at this level finishes with the final, graduation exam. Bachelor degree is granted.

Medical Informatics and Equipment Specialization

Studies at the Medical Informatics and Equipment specialisation provide future specialists in medical information acquisition, processing and communications as well as in developing, designing and maintaining medical equipment.

Information technologies courses group contains basic courses, e.g. low-level, structural and object-oriented programming, software engineering, computer graphics, web design etc. Contemporary engineering tools are also introduced for prototyping, simulation and evaluation of information systems. Methods of numerical data analysis, signal processing and statistics are presented. Basic and advanced techniques for image processing and recognition are taught. Courses introducing text and image databases as well as telemedicine are available.

Adepts of Medical Informatics and Equipment have a unique opportunity to study specialized medical systems:

1. Strong emphasis is put on functioning and requirements of radiological, hospital, laboratory (and similar systems). Necessary medical and social background is presented. Current regulations are discussed.
2. Backbone medical systems are presented. Functioning of image databases and communication between acquisition devices (like the Computed Tomography device) is explained. Medical data formats are introduced, data security is explained.
3. Computer aided diagnosis and therapy systems are presented and developed during various courses and projects (Fig. 2). Image analysis and recognition techniques are employed. Neural networks and other methods of artificial intelligence are shown.
4. Biocybernetics systems are introduced and discussed.

Fig. 2. Computer aided diagnosis application project.

The second group of courses available at the speciality, focuses on design, development and maintenance of various kind of medical equipment. Essentials of circuit theory, analogue and digital electronics, automatic control and mechanics are taught. Specialized systems are discussed, including:

1. Various signal acquisition and processing devices, e.g. ECG, EMG, EEG acquisition devices are discussed in medical and technical context. Safety regulations are presented.
2. Rehabilitation, therapeutic and diagnostic equipment is shown. Mechanical, material and software aspects are discussed.

Students of this specialization are prepared to work in:

- software companies as designers, analysers, developers and maintainers of specialized medical systems, etc.
- medical equipment manufacturing companies, as designers, developers and technicians,
- hospitals, as system specialists, system administrators, network specialists, equipment service staff, etc.
- research centres, during development of customized or experimental data processing methods and devices.

Medical Products Engineering Specialization

Students interested in design and development of medical products are encouraged to take the specialization of Medical Product Engineering. Adepts of this specialization have essential knowledge in biomedical engineering, with special emphasis put on biosystems, biomeasurements, artificial organs, biomechanics and rehabilitation engineering, biomaterials, information and communication systems, medical imaging and physics.

Different groups of courses are available to prepare students for future work and research:

1. Material and device engineering courses present a broad spectrum of methods of design and evaluation of desired material features for biomedical use.
2. Biomechanics courses present the knowledge necessary to understand functioning of live organisms. Selected aspects of human mechanics are presented in details to permit better design and development of both medical equipment and prostheses.
3. Advanced software tools are introduced to improve the quality of engineering process (Fig. 3).

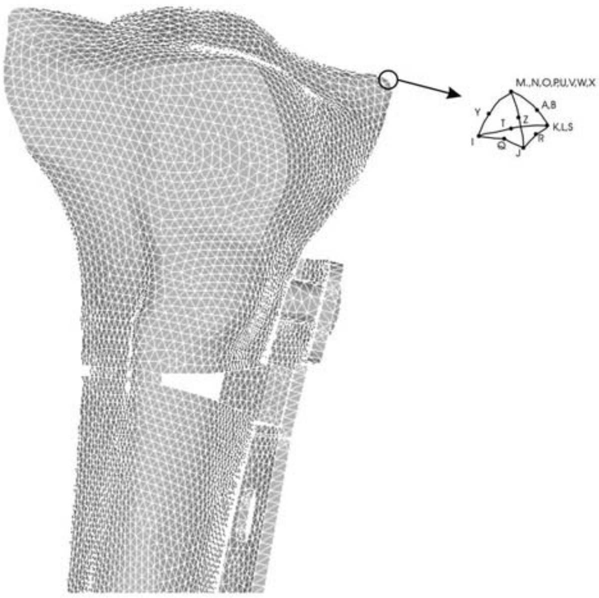

Fig. 3. Engineering process at medical products engineering specialization.

The graduates are skilled in the application of latest diagnosis and therapeutic systems based on information and communication technologies as well as electronic and material techniques.

They are also prepared to:

1. cooperate with physicians in integration, efficient utilization, service and maintenance of medical devices and therapeutic systems;
2. participate in design and manufacturing of medical devices, especially implants, instrumentation as well as hospital and rehabilitation devices;
3. participate in research and development in the field of biomedical engineering.

Students of this specialization are prepared to work in:

- hospitals, clinics, out-patients departments and other units of healthcare;
- medical device manufacturing companies and commercial companies as experts in the field of medical devices,
- technology centres of design and construction of medical devices,
- research and development centres as consulting engineers,
- the field of medical administration.

Postgraduate studies

Graduates from Biomedical Engineering (B.Sc.'s) as well as students of related disciplines (Biomaterials, Information Technologies, Medical Science, etc.) may continue their education during the full time, three semester 2nd degree studies. Advanced topics are available for ca. 90 students at different specializations: Informatics in Medicine, Biomechanics and Medical Equipment, Engineering of Manufacturing Implants, Hospital and Rehabilitation Equipment, Electronic Medical Equipment, and Sensors and Biomedical Information Processing. Due to a high specialization, courses available there overlap only in a limited scope (including basics of medical systems, biomedical modelling or genetic engineering). During the second and third semester master thesis is prepared and defended by all students. Master's degree is granted.

Informatics in Medicine

Specific applications of computer sciences into medicine are the field of Informatics in Medicine. At the specialization, various aspects of the cooperation are presented, which is necessary for students to be able to satisfy the functional requirements of authorized physicians for the benefit of patients.

Students of the specialization participate first in courses presenting basics of software engineering, high-level programming languages and software tools. At the next step, diverse issues of: speech analysis, biometrics, image processing, fuzzy data analysis and various computer medical systems are presented. This knowledge is then applied to design and implement various systems dedicated to assist physicians in the diagnostic process and therapy.

Throughout the studies, complex systems used in the radiodiagnostic process, medical imaging, computer aided diagnosis and therapy as well as navigated, minimally invasive surgery are discussed in details.

Students preparing their master thesis develop projects related to:

- medical informatics and telemedicine,
- computer aided diagnosis and therapy,
- medical information systems,
- biometrics.

They are ready to participate in interdisciplinary projects regarding advanced use of methods of data acquisition, communication, storage, processing and security. They are ready to work in hospitals and healthcare centres as well as in software and medical enterprises.

Biomechanics and Medical Equipment

Biomechanics specialization is focused on various aspects of mechanics and engineering methods in context of biomedical applications. During the studies, candidates for master's degree are first presented with essential knowledge from mechatronics, material engineering, biomechanics and ergonomics. This knowledge is later used for more advanced topics. Medical robots are introduced. Functioning, design and development process of bioprostheses is shown. Sport-specific problems are explained. Design of medical equipment, including tools and rehabilitation devices is taught. Advanced virtual modelling and computer aided design methods are presented.

Specific problems are discussed during various courses throughout the studies, including designing and optimization of manufacturing process in medical equipment, experimental methods in contemporary biomedical engineering, rehabilitation engineering and others.

Completing their education, during master thesis preparation, students:
- design implants and prostheses,
- design medical equipment,
- carry out various experimental tests in laboratories (e.g. human motion analysis or body scanning),
- use advanced engineering software.

Engineering of Implants, Hospital and Rehabilitation Equipment

Adepts of Engineering of Implants, Hospital and Rehabilitation Equipment have knowledge both in material and device engineering processes. Basic courses give insight into metallic, ceramic and synthetic biomaterials used in various medical devices, implants and prostheses. Methods of: surface engineering of biomaterials, corrosion and degradation processes evaluation, testing biomaterials and tissues as well as design and quality evaluation of instrumentation are presented.

At the next phase, the design of equipment used during bone and minimally invasive surgery, development and manufacturing of hospital and rehabilitation devices, techniques of virtual imaging as well as modelling and design of medical devices with the aid of computer techniques are discussed. Certification procedures of medical devices are also explained.

Moreover, the graduates have basic training in information technologies applied in medicine, modelling of structures and biological processes, tissue and genetic engineering and rehabilitation engineering.

The future masters of science are prepared to work in hospitals, clinics, research institutes and medical enterprises as well as to:
- work in the environment of engineers and physicians,
- design and manufacture implants, instrumentation,hospital and rehabilitation devices,
- solve research and innovative problems, and implement new solutions.
- prepare the documentation required in the certification process of medical devices.

Electronic Medical Equipment

Electronics science applied to the medical application is a domain of Electronic Medical Equipment specialization. Throughout the studies, students are familiarized with various functioning aspects of modern medical equipment. Basics and advanced issues of circuit theory, electromagnetic field, analogue and digital electronic components and microprocessor systems are taught at first. At the next step, advanced medical equipment and devices are presented.

During the studies, a unique opportunity exists to focus on
- design and implementation problems related to medical robots development,
- details of advanced medical devices functioning,
- functioning of state of the art image acquisition machines.

Interdisciplinary courses related to computer aided surgery and image-guided, patient specific navigation are also conducted.

Sensors and Biomedical Information Processing

A specialized class of electronic medical equipment – medical sensors, as well as methods of automated information processing are subject of the Sensors and Biomedical Information Processing specialisation. At this specialisation essential knowledge of digital electronics is presented first. Standalone and embedded microprocessor systems are introduced as a platform for fast and reliable data acquisition and processing. Various sensors are discussed in terms of design, use cases, and limitations. At the next step, advanced data processing approaches are introduced. Artificial intelligence methods are presented. Finally, issues of design and development of specialized medical equipment are presented, including:
- medical robotic systems,
- minimally invasive surgery tools and systems,
- navigation systems for computer aided surgery.

Ph.D. studies

The most skilled students with M.Sc. degree are encouraged to continue their education during the 4-year doctoral studies. At the beginning of these studies advanced problems of biomedical engineering and biocybernetics are presented in a series of high-level courses. Later emphasis is put on individual work. Topics within the discipline are researched by candidates to the title under the supervision of an experienced tutor. Ph.D. dissertation is prepared. After a series of doctoral exams and a successful public defence, a Doctor of Philosophy academic degree in Biocybernetics and Biomedical Engineering discipline is granted.

Recent dissertations defended at Silesian University of Technology in Biocybernetics and Biomedical Engineering within the Faculty of Automatic Control, Electronics and Information Technologies, have covered the following topics:
- various image-based computer aided diagnosis methods,
- fuzzy processing of medical dats in the diagnostic process,
- image recognition,
- pattern-based image processing,
- speech recognition,
- automated classification of medical data,
- wavelet and neural-network based biomedical signals and events processing,
- automated analysis of heart development.

Student projects

Two scientific circles are available for students of biomedical engineering under the course of studies where they are encouraged to develop projects on the basis of their own ideas.

The Scientific Circle of Biomechanics was established already in 2000 and has been supervised by the current staff of Faculty of Biomedical Engineering. Within the circle activities students carry out their own researches, designing medical devices and equipment. Best projects are presented during poster session on scientific conferences for young scientists.

For circle members, special trips are organized to the medical equipment companies or to rehabilitation and medical fairs. Invited lectures are organized.

Younger Scientific Circle of Biomedical Engineering has operated since the beginning of Biomedical Engineering specialization in 2007. Various software projects are conducted under supervision and guidance of faculty's members. Video processing, medical systems and computer aided surgery applications are designed and created by students. They are also encouraged to participate in research projects regarding data processing.

Furthermore, students can creatively and actively shape issues developed within the biomedical engineering students scientific association *Hybryda.* Individual and team-work in the field of research and development as well as participation in scientific meetings and symposiums are possible.

Broad view

Current education programme at the Faculty of Biomedical Engineering is constantly updated to meet requirements of students, industry and medical environment. When biomedical engineering started in 2007, only one specialization had been available for students. This has changed in 2009, when two distinct specialisations have been introduced into undergraduate studies. Comparing to the 2007 increased is also a level of biomedical, general courses available during first year of education. During these years a number of additional, non-mandatory courses have been started based on students' demands.

A lot of self initiative is also permitted during graduation project and thesis work, when students are permitted to submit their own ideas. A cooperation is started to permit training in medical and technical centres. Students are encourage to participate in exchange programmes and scientific meetings to share the know how.

The biomedical engineering as an interdisciplinary domain is likely to evolve in future. Adepts and researchers will shape a new face of industry and necessary changes will be incorporated into future training.

Research base

The new Faculty of Biomedical Engineering consists currently of four departments.

- Informatics and Medical Equipment.
- Biomaterials and Medical Devices Engineering,
- Biomechatronics,
- Biosensors and Biomedical Signals Processing.,

constituting interdependent units. Their members are experienced researchers and in many cases have been personally involved in organising the new faculty.

At the Faculty, three scientific meetings are organized: Information Technologies in Biomedicine (ItiB), Biomedical Engineering in Dentistry (IBwS) and a scientific conference for young scientists – "May's Meeting of Young Scientists of Biomechanics".

Research topics

Different aspects of biomedical engineering are researched in each of the departments. Members of individual departments have a long tradition of scientific work and are involved in many term projects, grants and enterprises regarding the domain. A close cooperation is also present between the faculty and the Centre of Biomedical Engineering.

Informatics and Medical Equipment

Research conducted by the department is focused on different medical systems. A lot of effort is dedicated to improve the diagnostic process by automation of image and data analysis and recognition. Various computer aided diagnosis systems emerge to relieve physicians in the time consuming analysis of Magnetic Resonance or Computed Tomography data. Processing methods that are designed and implemented in the detection of brain tumours, Multiple Sclerosis lesions, or Sarcomas resemble the work done by experienced diagnostic experts, shortening the diagnosis time. Images are analysed and affected regions outlined and visualized. Quantitative description and follow-up comparison is possible. Cooperation with major clinical hospitals of the Silesian Medical University as well as local medical companies is maintained.

The field of computer aided surgery is Also explored. Methods and equipment are developed in order to plan and conduct minimal invasive surgery interventions based on the pre-operation medical imaging. Virtual models of organs are created, visualization and necessary software are provided to surgeons. Grants of Polish government are used to increase the availability of modern techniques in the medical field.

Various biomedical signals are analysed. Diagnostic patterns are detected. Biometric features are registered and employed in the security and safety systems.

Medical information systems are researched. Distributed medical systems, image archiving network and data acquiring solutions are developed and evaluated.

Biomaterials and Medical Devices Engineering

In the department, research on biomaterials and biomechanics properties is conducted. Advanced medical materials and devices are developed to be used in surgery, dentistry, prosthodontics and osteosynthesis. For improved robustness, test are performed with preclinical and clinical conditions reproduced.

Within the department's research, optimization is performed on geometry, physiochemical and utility properties of implants for reconstruction and operative surgery. Analysis of stresses and deformations of implants used for treating fractures and long bones is performed.

Tests for the chemical composition and phase structure of metal biomaterials using qualitative and quantitative methods are developed. The required mechanical features are designed into metal biomaterials (e.g. alloys with a determined modulus of elasticity, superelasticity and shape memory). Desired properties of good mechanical properties, resistance to corrosion and biocompatibility are obtained.

Research on new generation of controlled rehabilitation equipment (design, production, technical and clinical tests) is also performed.

Biomechatronics

The researches of the department's members focus on various biomechanics application. Currently the employees of the department lead a few grants supported by Polish Ministry of Science, that concerned with biomechanics of babies' skulls, lumbar spine, thorax and also the grants dealing with human motion analysis in medicine, rehabilitation and sport, and the projects concerned with the engineering support of the surgical treatment.

Identification of mechanical properties of human tissues are conducted via the experimental tests on the dedicated machines. Implants and prosthesis are developed combining current knowledge on automation, materials and mechanics. Analysis of athletes mechanics (e.g. volleyball players and ski jumpers) is performed. The cooperation with Polish Ski Federation and Centre of Sport of Silesian University of Technology is maintained. Tests at schools are performed to diagnose postural disorder in children.

Rehabilitation equipment and medical devices are designed and modified to obtain the optimal mechanical functions and ergonomics. Real life applications undergo exhausting test in Silesian Centre of Rehabilitation *Repty* in Tarnowskie Góry and Silesian Centre of Child's Health in Katowice. Efficiency of rehabilitation is increased by using designed measuring equipment.

Biosensors and Biomedical Signals Processing

Department's research focus on various uses of biosensors, bioelectronics and bioinformatics.

Researchers of the department actively participate in many scientific projects regarding signal processing techniques in medical applications – e.g. systems are designed and implemented in order to aid physicians in stroke diagnosis or to acquire and process gastrosignals. Active research is conducted to optimize and design new signal processing algorithms. New sensors are designed in order to optimize acquisition of various biosignals. Application in medical devices are prepared.

Department members cooperates with Foundation of Cardiac Surgery Development Zabrze in development of a surgical robot. Also a research in field of bioinformatics is conducted. Classification, reasoning and advanced computational methods are applied to processing of biosignals, gene analysis and others.

Centre of Biomedical Engineering

Sharing the same discipline and part of the staff, the faculty of biomedical engineering cooperates closely with the other university's biomedical unit – the Centre of Biomedical Engineering.

The Centre is involved in the realization of research programs financed by The State Committee for Scientific Research, European Union and other domestic and foreign agencies supporting scientific, implementation, training and promotion activities. Transfer of new technologies and products related to biomaterials and medical devices is performed.

Computer aided medical diagnosis and therapy equipment as well as management of hospital wards are researched. A new generation of rehabilitation devices is designed and produced. Clinical tests are performed.

Various activities integrating different research units are initiated in order to permit the application of novel and modern methods in the medical environment.

Laboratory base

Establishment of the faculty initiated a significant reorganization within the university units and permitted the foundation of new laboratories. A part of the antique factory complex Nowe Gliwice (Fig. 4) has been adapted for research and education. Various new equipment has been acquired and configured. Many existing laboratories have also been upgraded in order to permit biomedical activities. Among others, specialized bioengineering labs have been organized.

Laboratory of Computer Aided Minimally-invasive Surgery

In the laboratory, various aspects of minimally-invasive surgery are researched. Virtual models of organs are designed and visualized. New equipment is tested on artificial models. Ultrasonography and position tracking-based navigation software is deployed to help surgeons.

Laboratory is equipped with ultrasonography device, positon tracking systems (Fig. 5), laparoscopic system, surgery simulation stand.

Laboratory of Computer Aided Diagnosis

Laboratory is used during research on new methods of image-based computer aided diagnosis systems. Algorithms of image analysis and image recognition are tested. Radiological workstations are designed and developed in order to permit clinical tests of developed methods.

High-end equipment is available in the laboratory. 4D ultrasonography acquisition device, medical image database system, workstations with high medical monitors, specialized accessories are used during research and educational activities.

Fig. 4. *Nowe Gliwice*, location of new laboratories.

Fig. 5. Work in laboratory of computer aided minimally-invasive surgery.

Fig. 6. Equipment of laboratory of investigations on the mechanical properties of biomaterials and implants (contains manufacturer materials).

Fig. 7. Equipment of laboratory of integrated material processes in prosthodontics (contains manufacturer materials)

Laboratory of Investigations on the Mechanical Properties of Biomaterials and Implants

The laboratory is designed for testing of mechanical properties of biomaterials, implants, surgical instrumentation and determination of biomechanical characteristics of medical devices. The laboratory is equipped with general-purpose testing machine, universal hardness tester, microhardness tester, and 3D scanner (Fig. 6).

Laboratory of Integrated Material Processes in Prosthodontics

The laboratory is equipped with integrated work stand for prosthodontics, work stand equipped with 3D-ultrasonic navigator for diagnosis and therapy of temporomandibular joints, system for computerized analysis of occlusal contact forces and complete CAD/CAM system used in prosthodontics (Fig. 7).

Laboratory of Three-dimensional Human Motion Analysis

Currently located in cooperating ITAM Institute in Zabrze. It enable to perform a high-precision optoelectronic multifactor biomechanical motion analysis of the various movements: from normal or pathological gait to ski jumps.

The laboratory is equipped, among others in a few specialized stands: infrared cameras, treadmill with dynamometric platforms and wireless EMG set (Fig. 8), dynamometric platforms and treadmill – for measurements and analysis of pressure load under foot, motion parameters and lines of center of pressure during stance, gait and run, systems measuring the ground force reaction. Posture and mobility of human spine can also be determined in specialized equipment (Fig. 9).

Fig. 8. Movement analysis in *BTS SMART* system

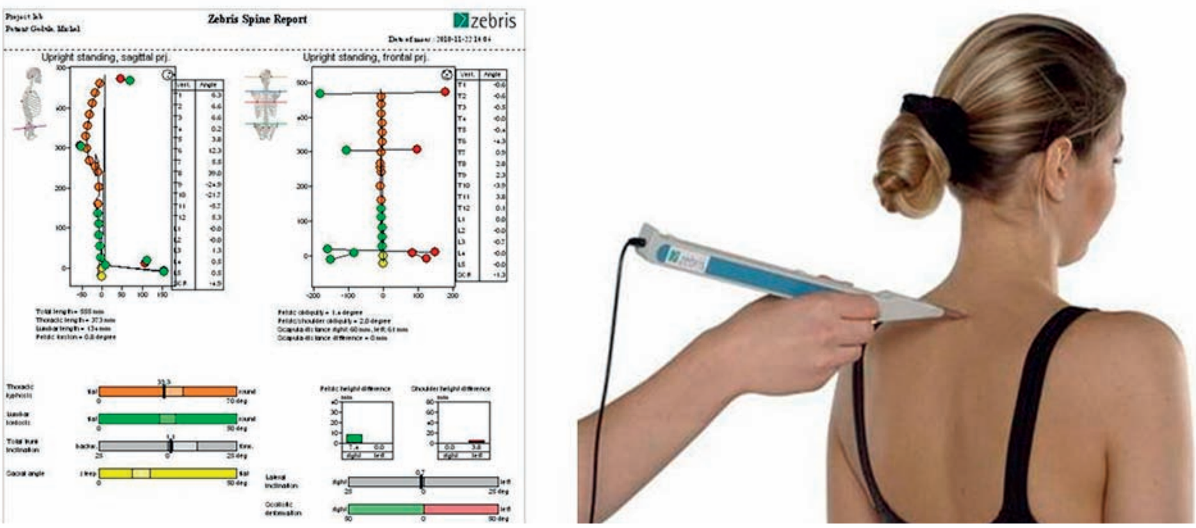

Fig. 9. Posture and mobility of human spine determination in *Zebris* system

Laboratory of Virtual Reality

Equipped in Automatic Virtual Environment enabling 3D projections of pictures, movies, projects and the 3D Body Scanner enabling precise and spatial measurements of object geometry and generation of 3D computer models.

Many other laboratories are also available for researchers and students, like:

- Biomedical information processing laboratory – permits testing various methods of biosignal data processing and it's equipped with computational cluster, signal processors, sensors and necessary computer workstations.
- Computer graphics and modelling laboratory, with specialized, engineering software for 2D and 3D modelling.
- Telemedicine laboratory, equipped with operating room teletransmission system, cardiologic surveillance system.
- Biometrics laboratory, with palm and iris scanners, tablets (Fig. 10) and specialized audio and video devices.
- Biosensors laboratory, with diversity of electronic bioacquisition devices.
- Light microscopy laboratory designed for preparation and microscopic observations and structure testing, equipped with complete work stand for materialographic preparations for light microscopy and system for automatic image analysis.
- Laboratory of surface treatment – dedicated to surface treatment by means of chemical and electrochemical methods and equipped with current generators, fume hood and electric furnaces.
- Laboratory for corrosion testing of biomaterials – for corrosion testing of metallic biomaterials, implants and surgical instrumentation in dedicated physiological solutions and in adequate conditions of implants use.
- Laboratory of testing the mechanical properties of human tissues – consisting of specialized for static and dynamic measurements of materials mechanical properties.

Fig. 10. Biometrics laboratory: analysis of human writing

Broad range of topics covered by research conducted by faculty's members as well as a constant engagement in national projects and industrial cooperation permit a constant improvement of laboratory base. New laboratories and specialized equipment will be developed or acquired.

Cooperation

During years of biomedical engineering activities, a number of cooperating institutions have been involved in common projects and research work. These include among others:

1. Health centres and institutions: clinics of the Silesian Medical University, Maria Skłodowska-Curie Cancer Centre and Institute of Oncology Gliwice, Upper Silesian Children Health Institute, Repty Silesian Rehabilitation Centre in Tarnowskie Góry, Neurosurgery and Neurotraumatology ward of Regional Specialised Hospital No. 4 in Bytom, Department of Surgery of the Cedars-Sinai Medical Centre Los Angeles, USA, EMC Medical Institute and many others.
2. Research institutions: Foundation of Cardiac Surgery Development Zabrze, Medical University of Silesia, University of Silesia, The Institute of Theoretical and Applied Informatics of the Polish Academy of Sciences,, University of Physical Education Katowice, University of Physical Education in Poznań, Automotive Industry Institute in Warsaw and many others.
3. Imaging centres: HELIMED Silesian Center for Diagnostic Imaging and VOXEL Medical Diagnostic Centres.
4. Medical systems and equipment manufacturing institutions: ITAM – Institute of Medical Technology and Equipment in Zabrze, Alteris Ltd.. Katowice, Philips Healthcare Warsaw, WASKO Inc., Medi.com Ltd.

A significant cooperation is also carried within various associations. E.g. the BIO-FARMA Consortium permits major local medical centres to obtain financial resources, the EuroPACS association and European Society of Radiology unite researchers of computer aided diagnosis systems etc.

Summary

Biomedical engineering has been available at the Silesian University of Technology for over forty years. Over these years various attempts have been made at different faculties to cooperate with medical institutions in order to improve the overall health care. Only recently, however, Polish law has been updated to allow education within the biomedical engineering discipline. This permitted the establishment of the full time undergraduate and postgraduate studies and shortly after resulted in the foundation of Faculty of Biomedical Engineering.

Studies available at the new faculty represent major branches of biomedical engineering, including biomechanics, medical informatics, biomaterials, biomechanics, biosensors and medical equipment. Cooperation between the faculty and healthcare centres, enterprises and research centres stimulates research activities and delivers new technologies.

The adepts of biomedical engineering studies are prepared to work in hospitals, companies, and research centres. Their interdisciplinary knowledge permits to cooperate with physicians, medical personal as well as engineers of different disciplines.

BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 47-50

TEMPUS IV PROJECT „CURRICULA REFORMATION AND HARMONISATION IN THE FIELD OF BIOMEDICAL ENGINEERING CRH-BME"

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Abstract: In the paper the aims, main objectives and preliminary results of the of CRH-BME project are presented, after 2,5 years of its running. The consortium is characterised as well as activities realised within the project are described. The project, coordinated by the University of Patras in Greece, is currently in the phase of dissemination of its results, however, for some Work Packages, final reports are still under construction. Implementation of the project results, mainly generic curricula for study programmes in the area of Biomedical Engineering, can lead to improvement of compatibility and harmonisation as far as education in this field is concerned, in the EU and Partner Countries (three countries from the Eastern Partnership are involved in the project: Armenia, Azerbaijan and Georgia). Thus, the impact of the project on students and teachers mobility can be achieved as well.
Keywords: Biomedical Engineering (BME), Higher Education Institution (HEI), Tempus IV, Eastern Partnership (EaP), Erasmus, student & teacher mobility, Quality Assurance

Introduction

The Tempus Project No. 144537-TEMPUS-2008-GR-JPCR "Curricula Reformation and Harmonisation in the Field of Biomedical Engineering – CRH-BME" was one of 66 projects accepted by the European Commission in 2008. In 11 of them, partners from Poland were involved.

The project started on 05.01.2009, with budget over 1.000.000 Euro for 3 years duration [1], and is realized by the Consortium consisting of 23 universities from 20 EU and Partner Countries (Armenia, Azerbaijan, Croatia, Georgia, Israel, Serbia and Slovenia). Three of them: Armenia, Azerbaijan and Georgia belong to the group of Eastern Partnership (EaP) countries, one of priorities of the current Polish Presidency in the European Council.

Following HEIs are involved in the CRH-BME project: University of Patras, Vrije Universiteit Brussel, Technical University of Varna, Masaryk University in Brno, Tallinn University of Technology, University of Oulu, Institute of Biomedical Technology, Technical University of Crete, Budapest University of Technology and Economics, University of Bologna, University of Naples – Federico II, Riga Technical University, West Pomeranian University of Technology, Szczecin, University "POLITEHNICA" of Bucharest, University of Ljubljana, Universidad Politécnica de Madrid, Karolinska University Hospital, University of Zagreb, The Hebrew University of Jerusalem, Faculty of Electrical Engineering, Belgrade, Orbeli Institute of Physiology, Khazar University, Georgia Technical University, University of Strathclyde. Almost all partners have extensive experience with international projects and collaborated previously within TEMPUS, ERASMUS, and other EU programmes. Faculty of Electrical Engineering of the West Pomeranian University of Technology, Szczecin, represented by the author of the current paper, is the only project participant from Poland.

Fig. 1. The CRH-BME project partners. 1st General Assembly Meeting in Patras, 2009

The project is coordinated by Prof. Nicolas Pallikarakis from the University of Patras, Greece. This university has a long-time experience in internationalisation of studies in the field of Biomedical Engineering. Since 1989 Prof. Basil S. Proimos, and then Prof. Pallikarakis, have organized a European Course in Biomedical Engineering and Medical Physics as well. This postgraduate programme has been run in collaboration with 25 universities in the EU contributing both in student and highly qualified teaching staff [2]. University of Patras was also coordinating the TEMPERE (Training and Education in Medical Physics and Engineering Reformation in Europe) project. TEMPERE was a European thematic network under the SOCRATES Programme, which was run between 1996 and 2000 and addressed the main issues concerning education, training and accreditation of biomedical engineers and medical physicists. Of particular value was formulation of a multidisciplinary competency based analysis of education and training needs, as part of an overall framework for Quality and Mutual Recognition of Education and Training. As an outcome there was a number of recommendations proposed, which were disseminated through an IOS Press publication [3]. This process also led to establishment of the extended network which involved a number of partners from all target groups, i.e. universities and training institutions, accreditation bodies and professional associations, as well as professionals from hospitals and industry. The author was involved as a partner in some TEMPERE project activities, mainly in workshops as well as one-year (2001) project "TEMPERE – dissemination year".

Biomedical Engineering is a field undergoing dynamic evolution during the last decades. Advances in biomedical research and the resulting development of new diagnostic and therapeutic methods, technologies and equipment, lead to a radical change in the way health care is delivered today. This development is characterised by increased degree of diversification. Biomedical Engineering is therefore rapidly changing, and becoming more and more attractive as a profession [4].

In Europe today there are an impressive number of universities offering both undergraduate and graduate studies in the field of Biomedical Engineering. Biomedical engineers should be prepared to meet existing, or forecasted needs in the form of knowledge, skills and attitudes that address these demands of the work environment in the broader health care related sector. This involves academia, medical industry, hospital facilities, as well as administration and management, in turns imposes new challenges for advanced education in this field. It is therefore necessary to review the educational structures on BME and adapt them to this new situation.

Main objective of the CRH-BME project is to update existing curricula and syllabi in the field of Biomedical Engineering in order to meet recent and future developments and address new emerging BME job market demands.

The objective will be achieved by:

- extensive review of the curricula in the field of BME education,
- investigation of the current and future demands in the medical device industry market,
- preparation of generic programmes on graduate and postgraduate education in BME.

Other specific objectives can be characterized as follows:

- promotion of the development of new study programmes,
- investigation of the possibilities for joint degrees,
- provision of a template guidance document for Quality Assurance,
- BME laboratory modernisation in the HEIs from Partner Countries,
- promotion of international teacher and student exchange mobility,
- dissemination of project results and sustainability, mainly by development of thematic networks in Partner Countries.

The last objective includes renewal of the TEMPERE European thematic network with participation of the EU neighbouring countries as well as its enlargement.

The goals of the CRH-BME project are in good correlation with „flagship initiatives" of the EU 2020 Strategy: Youth on the Move and An Agenda for New Skills for New Jobs.

Main activities and preliminary achievements

Activities carried out within the CRH-BME are organized in Work Packages, according to the project objectives. Effective cooperation of the project participants is possible thanks to General Assembly Meetings (GAM), workshops and short visits. The Internet is extensively used for work with questionnaires as well as for making comments on preliminary versions of reports and other material.

Five GAMs were organized in Patras, Dubrovnik, Porto Carras (Chalkidiki), Ljubljana and Oulu, and the sixth will be held in Budapest. Two workshops took place in Belgrade and Yerevan, two next are planned: in Tbilisi and Zagreb.

The project is currently in the phase of dissemination of its results, mainly by presentations on conferences [5, 6]. For some Work Packages, final reports are still under construction.

Fig. 2. The CRH-BME Workshop in Yerevan, 2011: Prof. Nicolas Pallikarakis, and discussion with a group of students interested in visits to partner HEIs in EU; one of them will come to Szczecin this year for 1,5 month

Fig. 3. The author presenting the CRH-BME project at the Eastern Dimension of Mobility, Eastern Partnership Conference in Warsaw, 2011 [6] and Prof. Sergo Dadunashvili from Tbilisi (right) discussing with Dr. Bogdan Broel-Plater (left) during his visit in labs of the Faculty of Electrical Engineering, West Pomeranian University of Technology, Szczecin, 2011

Within the first of Work Packages, review of the existing BME programmes in Europe was carried out. The results, for 46 countries in Europe investigated, are as follows:

- 40 countries have BME programmes;
- ca. 150 universities across Europe offer 299 BME programmes (!), including:
- 82 – undergraduate level, BSc,
- 217 – postgraduate level: 157 MSc, 60 PhD (~ 27 % BSc, ~ 53 % MSc, ~ 20% PhD);
- ca. 90 % of BME programmes offer ECTS,
- ca. 75 % of BME programmes have foreign students,
- ca. 70 % of BME programmes have Bilateral Agreements with foreign HEIs.

Generic programmes for graduate and postgraduate studies in Biomedical Engineering were elaborated within the "core" Work Package. The results are as follows.

Five generic types of BME programmes are envisioned based on previous experience and gathered information about specific needs in different environments:

- 1st cycle BME programme for employment,
- integrated 1st and 2nd cycle BME programme,

– stand-alone 2nd cycle BME programme with entry from 1st cycle BME programme,
– stand-alone 2nd cycle BME programme with entry from 1st cycle engineering or physical sciences programme,
– stand-alone 2nd cycle BME programme with entry from 1st cycle medical or biological programme.

Generic BME Curriculum for all types of programmes consists of seven BME Core Topics, defined after a long and difficult discussion of the Consortium members:
– Biomaterials,
– Biomechanics,
– Biomedical data and signal processing,
– Biomedical instrumentation and sensors,
– Health technology design, assessment and management,
– Information and communication technologies in medicine and healthcare,
– Medical imaging and image processing,

(any particular BME curriculum should contain at least four of them), and a number of BME Elective Topics.

The project participants elaborated syllabi for the BME Core Topics, together with assigned ECTS credits.

Recently at the Faculty of Electrical Engineering of the West Pomeranian University of Technology, Szczecin, attempts have been made aimed at updating existing curricula in the field of BME, based on the CRH-BME project results. New curricula are elaborated in cooperation with other faculties of the West Pomeranian University of Technology, mainly the Faculty of Chemical Engineering, and some departments of the Pomeranian Medical University in Szczecin (mainly the Department of Medical Physics).

Conclusions

Implementation of the project results, mainly generic curricula for study programmes in Biomedical Engineering, should lead to improvement of compatibility and harmonisation in this field of education, in the EU as well as Partner Countries. Also, the impact of the project can be achieved on internationalisation of studies, on students and teachers mobility. As far as the exchange with the Partner and Eastern Partnership Countries is concerned, main problems identified within the project in this area arise from limited number and duration of flows and language problems; some participants reported also visa problems.

Among some ideas for the future, one can shape a postulate of closer integration and smooth transition between EU educational programmes, with increased flexibility and not complicated procedures („user friendly" programmes).

In the author's opinion, there is also need for organizational and financial support from the EU in forming special cooperation platforms and networks dedicated to active student groups and leaders (e.g. student scientific/research groups). Student Research Group in BME „Akson" from the Faculty of Electrical Engineering, West Pomeranian University of Technology, has just started such informal cooperation with students from Yerevan and Tbilisi.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 51-57

THE IMPORTANCE OF THE COMBINED TEACHING AND RESEARCH WORK IN THE EDUCATION OF BIOMEDICAL ENGINEERING

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Abstract: The purpose of the work is to present specific and difficult problems connected with scientific investigations and education in the interdisciplinary field what there is biomedical engineering. In our Division of Metrology and Optoelectronics, research works are combined with teaching duties. Our investigations in biomedical engineering are mainly based on utilization of light-tissue interaction. Interests include research and developing of measuring systems, evaluation of the uncertainty of measurement results, and improvement of instrumentation used in biomeasurements. The conducted by us speciality *Measuring Systems in Industry and Biomedical Engineering* (SPPIB) is the interdisciplinary speciality offered to the students at Faculty of Electrical Engineering at PUT. The Engineer's and the Master's programs of the speciality offer several courses enabling greater depth knowledge and practical experience to students.
Keywords: biomedical engineering, teaching and research, interdisciplinary speciality

1. Introduction

Poznan University of Technology is rated among the best Polish universities. It is autonomous state institution consisting of ten faculties providing didactics for 20 000 students. The academic staff members do research and run educational tasks. The Faculty of Electrical Engineering of the Poznan University of Technology conducts the courses in a three-degree system: the engineer's, master's, or doctor's courses [16]. The students have a choice of full time or extramural studies. The speciality *Measuring Systems in Industry and Biomedical Engineering* (SPPIB) which is currently offered to the students by the Division of Metrology and Optoelectronics, is more universal and there is a great demand for such interdisciplinary engineers. Obligatory courses include lectures, laboratories, projects and seminars. The ranges of the Engineer's and Master's theses are shown. The interdisciplinary nature of the topics is reflected in how the lectures and laboratory experiments are accepted and understood by students. The influence of important relation between teachers and students on efficiency of education should be taken into consideration.

Biomedical engineering based in both engineering and the life sciences relates to physiological phenomena as well as to electrical, optical, mechanical, chemical, physical and other principles to be applied in diagnostics and therapy [3, 5, 27, 28]. Interdisciplinary questions can generate innovation in different areas with the increasing interaction and cooperation between physicians and engineering researchers. There is also necessity to work well in a well-integrated interdisciplinary team. The Division of Metrology and Optoelectronics with the success built the investigative team which the major research areas focus on the two directions:

– Acquisition, processing and measurements of optical and biooptical signals,
– Metrological problems in interdisciplinary investigations with a special focus on the noninvasive biomeasurements.

The bibliography contains the selected publications of the members of the team and the subjects of the doctoral and post-doctoral dissertations.

2. Activity Areas of Division of Metrology and Optoelectronics

2.1. Research and Technical Interests

The Division aggregates the research and educational tasks. Our team is involved in the interdisciplinary areas: general metrology and measurement engineering as well as biomeasurements and biomedical engineering. Scientific and research activity includes such fields as:

- Metrology of electrical and non-electrical quantities and modern measurement engineering.
- Modeling of phenomena and objects, and conditioning of measurement signals.
- Design, construction, testing, and applications of the measurement and control equipment based on microcontrollers programmable systems, PLC controllers, specialized MEMS and MOEMS systems, measuring and signal sensors and converters.
- Computer-supported measuring systems.
- Assessment and measures of quality of electrical power and energy.
- Methods of identification of harmful electric power receivers with regard to dependence between variations of electrical signal supplying the light sources and oscillations of the light flux (light flickering).
- Methods, systems, and devices for processing and measurements of optical and biooptical signals.
- Spectrophotometric and spectrometric measurements.
- Measurements in opto-telecommunications.
- Thermovision measurements.
- The problems of image interpretation, with particular consideration of micro-images obtained from a CCD camera.
- Biomedical measurements and medical engineering with particular application of non-invasive diagnostic methods based on optoelectronic sensor technology.
- Noninvasive diagnostic methods used in medical engineering, with particular consideration of optoelectronic sensor technology and advanced imaging methods.
- Methods and systems used in biomedical measurements.
- Computational modeling and analysis in medicine.
- Methodology of experiment, and evaluation of reliability and uncertainty of measurement results.

We are specialists in different areas of metrology with special focus on electronic and biomedical measurements. Research interests among other things include biomedical optics and light-tissue interactions, and development of diagnostic devices for medicine using optical technologies. Our current research concentrates on mastering efficient transillumination of thick layers of tissues and building efficient and stable algorithms representing the anatomic and functional properties [15]. Transillumination as the method of examination by the passage of light through tissues or a body cavity is a diagnostic technique in the course of intensive development at the moment. Light scattering and absorption can complicate the transillumination image and decrease image resolution. However, from the combined imaging point of view, the optical imaging may provide information on the functional condition unavailable in X-ray and other techniques. Of course progressive development of noninvasive optical imaging and measurements always depends very much on the clinical acceptance of the advanced biomedical technology and engineering. Biomedical engineers are able to play a significant part in this process.

Investigations allow us to improve the scientific specialization of our Division and the developing our team. The team activities took various forms. Scientific and didactic experience in the interdisciplinary field of interest has translated into a lot of papers and authorship and co-authorship of several technical books and book chapters. Some examples of the results obtained by the authors are presented in selected publications as well as doctoral and postdoctoral theses listed in bibliography. These examples concern such works as: measurements of electrophysiological signals [9, 18], noninvasive monitoring of arterial blood oxygenation and pulse waveforms [1, 2, 4, 7, 8, 17, 26], design, testing, and applications of measuring sensors and systems [5, 10, 14, 15, 21-23, 25, 26], modeling of phenomena and objects [5, 18-20, 29], optical techniques supporting combined medical imaging [5, 11-13, 15], assessment and measures of electrical power quality and harmful light flickering [29-31].

Taking into account metrological aspects of all kinds of experiments, a measurement result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty is required in order to decide if the result is adequate for its intended purpose and to ascertain if it is consistent with other similar results. An uncertainty budget illustrates principles of uncertainty analysis taking into account possible correlations between contributing variables to be measured. Each uncertainty budget should contain such types of information which are important from the point of view of a given application. Health and safety should be concerned in medical as well as industrial and commercial applications. All working in the medical fields have to estimate the uncertainty of results [4, 5, 14, 18, 19, 23, 24, 31].

2.2. Scope of Educational Tasks

We teach the principal fields of study which are obligatory for all students at the Faculty of Electrical Engineering and a set of courses to be included in the curriculum of the elaborated speciality. Two subjects: *Metrology* and *Optoelectronics* are included in the program of the teaching at the Engineer's degree, while the subjects *Electrical measurements of nonelectrical quantities*, and *Measuring computer systems* are included in the program of the teaching at the Master's degree. Students learn how efficiently and safely to operate devices and systems used to gather, measure, and analyze data through hands-on experience in a laboratory. The choice of the content of the teaching is based on a close relationship between theory and practice. In our opinion, a larger role in the efficient education curricula should be always given to its laboratory and project segments.

The didactic and research laboratories are provided with high quality measuring equipment. There are among other things: analogue and digital measuring and recording devices; a specialist stand for biological signal measurements and pulse oximeters equipped with a set of sensors; specialist stands for: power and energy measuring, and radiometric measurements; high quality electric current source; thermal chambers, thermovision cameras; UV-VIS-NIR spectrophotometer and spectrometers;, semiconductor radiation sources of adjustable emission parameters; a programmable radiation source of adjustable and stable parameters of radiation power emitted by the head consisting of a set of electroluminescence diodes and a controller of laser CW diodes; a pulse radiation source energy meter of improved resistance to disturbance; a multi-component optoelectronic set serving for assembling of simple and complex variants of stands and measurement channels.

The courses are intended to stimulate student's activity and introduce them to important questions. A professional education must be an anchoring point, especially for active students. The major area is educational efforts attracting students to modern engineering fields such as: metrology, optoelectronics and photonics, computer measuring systems, and sensor-based systems which support many applications today in industry and medical engineering. Specialist training in the area of calibration, testing, and operating specialist measurement devices are of high importance. The increasing demand of experimental accuracy in all scientific areas makes instrumentation for biomeasurements and medical imaging a crucial component [24], particularly in higher education curricula with a strong technological element, being also essential at research and development level.

3. Speciality: *Measuring Systems in Industry and Biomedical Engineering*

3.1. Profile of the speciality

Candidates on the speciality are the third-year I Cycle studies (at the Engineer's degree) and the second-year II Cycle studies (at the Master's degree) faculty students, respectively. Master's degree programs take one and a half years to complete, in addition to the three and a half years needed for the Engineer's degree. The majority of these candidates combine engineering talents with an interest in medicine. They are interested in health and medical issues as well as in electronic engineering and computing and information technology. The successful meeting of different academic disciplines requires complying with carefully balanced components of both the technical and medical questions. The interdisciplinary nature of the topics is reflected in how the lectures, classes and laboratory experiments are accepted and understood by students.

We hope that our students will be talented researchers, innovative engineers and prospective authors of valuable publications. They are advised to present their good results in a way comprehensible for various readers, i.e. the specialists and those outside the speciality of the paper to understand quite easily. The speciality is designed to convey the basic knowledge of electronics, microprocessors, microcontrollers, sensors and transducers, instrumentation for measurements and object imaging used in industrial and biomedical devices as well as communication and data transmission in measuring systems. Education in these fields may prepare students with knowledge of technical and medical systems and devices, and help to resolve problems with application of electronic and electrical instrumentation. Training in biomedical engineering develops knowledge through courses in analysis and measurements of biological signals, sensor technology and medical imaging, fundamentals of biophysics. Particular courses teach students about the various devices and types of equipment used in industry and biomedical engineering.

3.2. Personal qualifications of candidates

Future engineers should be aware of responsibility for the management of industrial and/or medical equipment and other devices, scheduling quality assurance checks to ensure they are functioning correctly and safely. Current engineers should to specialize in diversity. Today, industry and healthcare technology are constantly changing to meet new needs. New advances very extend into information and communications systems and traditional industrial and medical equipments are more complex than ever.

A sophisticated level of scientific and technical knowledge is especially required for biomedical engineers, who bridge the gap between medicine and engineering. Biomedical engineers must have strong engineering knowledge and be prepared to keep up to date with scientific and medical research. They should have good communication skills to work well in a team and with a wide range of people.

An interest in electronic devices, measurement and instrumentation, mechatronics, photonics, telecommunication, information technology is very important. Moreover, an interest in physiology, medical instrumentation, clinical care of patients and in understanding and recreating the functions of various biomedical systems plays a great part. Specificity of speciality continually needs to update knowledge of technical and biomedical issues.

The speciality scope is also designed to be the area where students will have the opportunity to be introduced to the latest techniques and knowledge in sensor technology including biosensors as well as medical imaging and biomeasurements including their uncertainty evaluation. Initial knowledge: fundamentals of mathematics, physics, metrology and measuring engineering, electrical and electronic engineering, optoelectronics and photonics, electrical measurements of nonelectrical quantities, computer measuring systems.

3.3. Scope and form of education

Previous mastery in electrical and related engineering gives a very useful technical background to consider complex problems such as, e.g., electromagnetic wave propagation in tissues, acquisition, processing, measurements and imaging of biosignals. Efficient and safe application of biomedical engineering must meet the various human and technical needs such as: medical practice, ethics, clinical care of patients, instrumentation reliability, and material biocompatibility. Education is based in classical engineering, supplemented with a combination of courses in physiology, human factors, systems analysis, medical terminology, measurement, and instrumentation. The I and II Cycles studies programs of the speciality offer several opportunities for adding an extended dimension to the knowledge and the practical experience of a student.

The scope of the teaching depends on the type of studies and courses included in their programs. The program of education comprises several courses which include lectures, laboratory classes, projects, diploma seminars and student internships. All courses are obligatory. Each one presents a clearly defined learning objective, description of the content, initial knowledge, teaching and assessment methods. Assessment methods include, respectively, tests, reports on projects, tests and exams after the course.

The program of the speciality at the I Cycle studies (engineering) includes the following courses offered to students at the 7th semester:

– Electronic Converters of Signals (lectures and laboratory classes);

The student should obtain the knowledge of characteristics and applications of analog, analog-to-digital and digital-to-analog converters.

– Sensor Technology and Imaging of Objects (lectures and laboratory classes);

The student should obtain the knowledge of: modern measuring systems to be applied in studies of nonelectrical quantities (including biophysical quantities), as well as modern methods of image acquisition and analysis; metrological attributes and testing of selected modern measuring and monitoring equipment for biophysical applications; modern methods of imaging used in technology and medicine: thermovision, thermography, ultrasonography, computer tomography (CT), magnetic resonance (MRI), X-ray imaging (RTG), fiberoscopy and endoscopic ultrasonography (EUS); devices for acquiring images with visible radiation (CMOS and CCD converters); configuration of vision systems for image acquisition with analog and digital cameras; formats of graphical files and methods of data compression; methods of image digital processing.

– Virtual Measuring Devices (lectures and projects);

The student should obtain the knowledge of: modern techniques of measuring data acquisition, processing and presentation; selected examples of virtual measuring devices realization; principles of preparation of a user interface and program code by the use of LabVIEW environment; program realization of some selected functions of measuring devices.

– Measurements and Analysis of Biological Signals (laboratory classes);

The student should obtain the knowledge about modern methods of measurements, processing and analysis of biological signals. Noninvasive techniques are presented especially.

– Evaluation of Power Quality (lectures and laboratory classes);

The student should obtain the knowledge of fundamental problems of evaluation of power quality. Measures of voltage fluctuations and harmful light flickering caused by voltage variation are discussed in detail.

– Laboratory of Electronic Circuits (projects);

The student should obtain the knowledge of the fundamental principles of design, assembly, and using of electronic circuits. Practical studies include: design and a self-assembly montage of electronic circuits which meet proper requirements, principles to be binding during the electronic circuits assembly and use, and testing of designed circuits.

– Diploma Seminar (projects);

The student should obtain the knowledge about important questions concerned diploma thesis and techniques of its multimedia presentation.

The program of the speciality at the II Cycle studies (master) includes the following courses offered students at the 3rd semester:

– Application of Microcontrollers and PLC controllers in Measurements (laboratory classes and projects);

The student should obtain the knowledge of: fundamentals of programming of the selected PLC controllers and measurement capabilities of the modern 8-bite microcontrollers; examples of measuring systems configurations using a PLC controller; configuration of microprocessor system; measurement applications with internal I/O resources; cooperation between a microcontroller and external devices; application of microcontrollers in measuring systems; program environment for cooperation with microcontrollers.

– Design and Simulation of Electronic Systems (projects);

The student should obtain the knowledge of planning and analysis of the analog and digital electronic systems with computer application to aid the simulation of electronic circuits; design and analysis of properties of the selected electronic systems and carrying out the simulation studies using specialized programming environments.

– Selected Problems with Evaluation of Power Quality (lectures and projects);

The student should obtain the knowledge of: selected problems with evaluation of power quality in electrical networks; measurements of the harmonics and interharmonics of periodical and non-periodical signals; examples of noxious loads; influence of changes in the active and reactive powers on voltage variation; light flickering caused by voltage variation.

– Fundamentals of Biomedical Engineering (lectures);

The student should obtain the knowledge of: physical and medical fundamentals of biomeasurements and medical engineering to understand the methods and systems for measurements and diagnostics; selected elements of physiology and anatomy; thermodynamics of biological systems; physical background of medical diagnostics; modeling of biological processes; influence of electromagnetic radiation on tissues and protection of the organism from harmful factors; medical electronics and optoelectronics; medical applications of lasers; biosensors; elements of bioinformatics; selected questions of statistics and medical informatics; clinical engineering; ethics of procedures used in medical investigations.

– Diploma Seminar (projects);

The program includes: technical edition and formatting of research work, editorial requirements, reporting the results of experiments, and training in the ability to express oneself, examples of presentations.

The well organized lectures and laboratory exercises present to students interested in engineering, bioengineering and other related areas, a useful overview of measurement techniques and instrumentation. The courses provide interactive demonstrations and opportunities for hands-on experience on measuring devices and systems and are a valuable way to consolidate theoretical knowledge and discover some practical points. Held in a smaller group than most other general courses given before, the speciality courses enable students to pick up practical experience of important selected procedures, with teacher guidance. Graduates should be prepared to the independent and team work.

Potential supervisors of theses present their proposals during an open seminar and encourage students to carry out the diploma works. Everyone has the option of choosing between an experimental, constructional or conceptional subject. A student may also propose his own subject matter, e.g. such a thesis which has been co-ordinated with expectation of the future employer. The currently proposed and realized so far Engineer's and Master's theses are comprised in the range of the subject matter of the speciality such as:

- laboratory sets for noninvasive biomeasurements,
- measurements and analysis of biomedical signals,
- multi-point measuring systems for monitoring the body parameters,
- methods and techniques of object imaging,
- compact and dispersed measuring systems,
- applications of sensors for measurements of nonelectrical quantities,
- imaging of the selected object properties,
- measurements of materials properties,
- spectrophotometric measurements,
- computer-supported measuring systems,
- wireless transmission of measurement data with GPRS system and application of wireless interfaces in measuring systems of short distance,
- thermovision investigations of objects and diagnostic capabilities of infrared cameras,
- testing of influence of voltage fluctuations on the status of selected sources of light and electronic devices of the general use,
- experimental investigations of a flickermeter signal path,
- evaluation of power quality using daily and week's approach,
- bioclimatic facades,
- generation of visual test signals,
- information technology in measurements and virtual measuring devices based on Lab-View environment,
- design of smart wiring for the selected living quarters,
- microcontrollers in measurements and using of the programmable logic controllers PLC in intelligent buildings and industrial systems,
- testing of indication accuracy and uncertainty of measuring devices,
- pulse supplying of high-performance LEDs systems.

The "interdisciplinary" graduates and post-graduates can find satisfying employment because they have sufficient knowledge of more than one branch of engineering. The capacity to adapt to a variety of technical problems may be valuable feature for practical reasons related to a steady great demand for modern engineers. As the engineers that can play a role of "translators and interfaces" between the medical, technical, and business professions.

Because of the interdisciplinary nature of the speciality, the acquired knowledge and practical abilities make possible the employment in many branches of the science, technique and industry and in the protection of health and environment including such fields as clinical engineering, biomeasurements, telemedicine, medical computer science. Our graduates work in many places. The best job prospects are expected for engineers with master's degrees in the field. Holding a Master of Science degree qualifies graduates for a number of research and supervisory positions. Some of them also continue education on the III Cycle studies *Modern electrical and information engineering* at Faculty of Electrical Engineering and may pursue a doctorate degree.

4. Influence of relation between teachers and students on education efficiency

The purpose of the presented study is to discuss some interesting and difficult problems concerned with higher education on interdisciplinary fields. Sometimes, an important barrier depends here on that most teachers were trained in traditional disciplines and they must learn to appreciate differing perspectives and methods. Current students are usually characterized by positive approaches to learning, having more interest in science and having more self-confidence. A good "interdisciplinary" teacher should still love learning new things because development in biomedical engineering is rapid and growing. The example comes from the top, thus good teachers should give a good example based on their own scientific career. Teachers that actively cultivate their scientific interests are very accepted by students. You can see this in the moment of "taking" the subject of the diploma. Such way of the realization of the didactic tasks which makes possible active participation in them and discussion with the leader as well as colleagues to students favours this. One of the conditions that provides for good reports in contacts with the student and the efficiency of the teaching is the skill of balancing between formulating the requirements and treating the students with understanding. Teachers should be demanding but warm persons. Moreover, they should have a lot of time for students.

Our team is very well-integrated. Majority of the Division team have more than a decade of experience in leading a research and educational group at the Faculty of Electrical Engineering. Some current members of our Division were at first the graduate students and PhD students, today they cooperate on research and teaching. As the academics who have a passion for education, we try to promote science to our students by education programs and students chapters.

An interpersonal relationship usually involves some level of interdependence and may range from fleeting to enduring. To be a good teacher in biomedical engineering an academic teacher should have excellent communication skills for dealing with students and be able to work well in an interdisciplinary team. On the other hand, such teachers should have current excellent technical knowledge and continually update this knowledge. We enjoy being the mentors and helping the students to understand and discover the mysteries of biomedical engineering. One of the most important didactic tasks is to encourage the students to explore the complex interdisciplinary fields.

It is noticing that we as well our students and postgraduates participate in harmony in many cyclical promotive events to encourage visitors who are interested in studying at PUT, to decide on our modern and useful speciality. We also teach the students to organize their experience. Students like to be involved in shared organization of professional excursions as well as informal annual meetings which also play an important part in improving the teacher-student relations. These relationships benefit us and make teaching much more efficient. Since several years, Student Research Group *SENSOR* leads activity in the following sections:

- Biomeasurements and medical engineering,
- Sensor technology,
- Programming of microcontrollers.

The *SENSOR* members participate in seminars, conferences, and didactic tours. They also offer self-teaching program and participate in the organizing teams to be formed for the annual academic promotions such as the Faculty *Open Doors*, *Scientists Night*, and *Girls at the Technical Universities*.

It should be also emphasized that the annual university certificate of completion of studies ceremony is very important and emotional for teachers as well as the participating students, their families and friends. This unique closing ceremony includes some special talks, a concert and warm conversations in a relaxed atmosphere.

A set of some friendly and helpful guidelines for graduates may be as follows:

- Be brave and persistent.
- Surround yourself with friendly people.
- Be very active in your professional life.
- Get to know the useful vocabulary continually.
- Be happy to take on responsibility.
- Cultivate your scientific interests as well as your hobbies.
- You can do anything if you truly wish.
- Always remember an algorithm: you dream, you act, and you win.
- Where there's a will there's a way. Nothing succeeds like success.

It is exciting to cooperate with young scientists who were brought up at our university. We are proud to see our "academic children" getting great new results. Our team plans to continue work on developing the future path of the presented speciality, as it is pertinent to current trend in education of engineers of marketable interdisciplinary skills.

5. Conclusion

We are sure that the combined teaching and research work is of high importance in the efficient education of biomedical engineering. Biomedical engineers should be able to combine biology, medicine, and engineering questions and to use advanced knowledge of engineering and science to solve medical and health-related problems. Modern students at technical universities especially accept teachers who actively cultivate their own scientific interests. In our Division of Metrology and Optoelectronics, research works are combined with teaching duties. *Measuring Systems in Industry and Biomedical Engineering* (SPPIB) is the interdisciplinary speciality offered to the students at Faculty of Electrical Engineering of Poznan University of Technology. On the one hand the speciality SPPIB is more universal, and on the other hand the demand exists on such interdisciplinary engineers to conduct research resolving problems with design and operation of electronic and electrical industrial a well as biomedical instruments and systems.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 59-66

BIOMEDICAL ENGINEERING AT GDANSK UNIVERSITY OF TECHNOLOGY

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Abstract: Short history of education in Biomedical Engineering at Gdansk University of Technology is presented. The last initiative – implementation of the new programme, Biomedical Engineering – an interfaculty direction of study, supported by a grant financed by the European Social Fund is presented. Curricula of four specializations: Chemistry in Medicine, run by the Faculty of Chemistry; Electronics in Medicine and Informatics in Medicine, run by the Faculty of Electronics, Telecommunication and Informatics; and Physics in Medicine, run by the Faculty od Appled Physics and Mathematics are described in details.
Keywords: education, interfaculty studies, biomedical engineering

Introduction

Education related to biomedical engineering is present in *Gdansk University of Technology (GUT)* since 1973, when the first agreement of cooperation in research and education was signed between the *Medical University of Gdansk (MUG)* and *the Institute of Electronic Technology*, one of three institutes operating within the *Faculty of Electronics GUT*. As a result of this agreement courses of the specialization called *Medical Electronics* have been established and in 1976 first graduate students have been awarded MSc diploma of electronic engineering in this specialization. The specialization, under several names as: *Medical Electronics* but also as *Bio-Opto-Electronics, Medical and Ecological Electronics*, and finally *Biomedical Engineering (BME)* was constantly present at the faculty till today. A very important fact related to development of this specialization was formal establishment of *the Department of Medial and Ecological Electronics*, in 1991, renamed in 2003 to *the Department of Biomedical Engineering*. This year we are celebrating 20 anniversary of this department.

Further development of infrastructure devoted to education of BME was possible due to TEMPUS grants which have been awarded in 1994 and 1997 (*TEMPUS JEP 11550 CEMET – Centre of Medical Technologies*). The funds allowed of modern formation of staff in respectively ecological and medical technologies. One has to add that joining of both fields – medicine and ecology – is intentional as several diagnostic technologies used in both domains are the same or are based on the same principles. The second Tempus grant allowed for proper development of laboratories and for another step towards interdisciplinary education in biomedical engineering – opening of the specialization *Informatics in Medicine*, the first in Poland MSc courses of this kind, offered since 1999. Importance of our efforts was admitted at the national level – the Minister of Science awarded the Faculty of Electronics GUT by giving in 2002 the diploma of a centre of excellence in medical technologies.

For several Polish technical universities, with similar initiatives and having strong background of educational programmes related to biomedical engineering, supported by intensive research it was natural to establish formal platform for cooperation in this field at the national level. Also several important organizations gathering specialists working in biomedical engineering as *the Committee of Biocybernetics and Biomedical Engineering Polish Academy of Sciences, Polish Society of Biomedical Engineering* and some other strongly supported the initiative to establishing formal framework in education of biomedical engineering. The effect was reached in 2006, when the *Minister of Higher Education and Research* accepted *Biomedical Engineering* as a formal university study direction at all three levels – BSc, MSc, PhD – and formulated obligatory program minima for BSc and MSc levels. Additionally BIOMEN – the formal net of institutions existing in the field of biomedical engineering in Poland was established in 2004 [1].

In GUT three faculties: *Chemistry (WCh), Electronics, Telecommunication and Informatics (WETI), Physics and Applied*

Mathematics (WPAM) decided to cooperate and prepare curricula in common interdisciplinary courses of biomedical engineering. The first call for students was in 2008. At the same time we applied for a grant ***Przygotowanie i realizacja kierunku Inżynieria Biomedyczna – studia międzywydziałowe (Preparation and*** *realization of the study direction Biomedical Engineering – interfaculty studies)* to be financed by structural European funds – the human capital – PO KL. The application has been awarded positive decision for realization of the grant during the period 01.04.2009 – 30.04.2015 in cooperation with AGH University of Technology (AGH) and Warsaw University of Technology (PW), getting the highest ranked evaluation at the call. The following text is describing this initiative and showing organization of the *BME* study at GUT as well as discussing main problems we already met.

Biomedical Engineering as interfaculty direction of study – motivations and content

Common foundations

Organizationally coordination of the *BME* study is in hands of the *Programme Committee* acting as the *Steering Committee* of the project POKL, too. The Committee is meeting regularly every month discussing all important problems related to education, organization, monitoring etc. Prof. Antoni Nowakowski, head of the *Department of Biomedical Engineering* is also appointed as the coordinator of the project. Co-authors of this article are responsible for running specializations. All basic decisions are in hands of deans of the three faculties involved in running the BME study and the POKL project. Admission of students is performed at the WETI as the coordination faculty. Diplomas BSc and MSc in BME are given by the faculty of the chosen specialization.

Candidates for the first year of studies are accepted in the course of admission procedures, which in general are the competition of results of school reports. Admission within the place limit is decided by the sum of points in given subjects:

- math or physics and astronomy or informatics or chemistry,
- Polish and one foreign language.

The first level of education, undergraduate studies, assuring engineering diploma, lasts 7 terms (semesters). Generally, we offer education in four specializations, called streams at the first level of education: *Chemistry in medicine (ChM), Electronics in medicine (EM), Informatics in medicine (IM)* and *Physics in medicine (PhM)*. The awarding of Bachelor of Engineering (BEng) diploma requires the acquisition of no less than 210 ECTS points during 7 semesters. An academic year of day studies is equivalent to 60 ECTS points.

The second level of education, graduate studies, assuring diploma of master in engineering MSc (magister inżynier) lasts three following terms. The awarding of MSc requires the acquisition of not less than 90 ECTS given during 900 hours of lectures, tutorials, laboratories and projects. It gives the right for further scientific study at the PhD level.

Graduates have a basic knowledge on biomedical engineering, including medical informatics, medical electronics, medical physics, biomechanics and biomaterials engineering. The graduate has ability to use modern equipment and systems for diagnostic and therapeutic use, based on methods and techniques of teleinformatics and information technologies, electronics, medical physics and material sciences. Graduates are prepared to cooperate with medical doctors in the integration, operation, usage, and maintenance of medical equipment. They service diagnostic and therapeutic systems and contribute to the production and design of medical devices or diagnostic and therapeutic systems. They are prepared for participation in the research in projects dealing with biomedical engineering. The graduate should have skills allowing competences acceptable as a clinical engineer, after proper practical experience in a hospital, according to legal regulations.

Graduate is prepared to work in: hospitals, clinical units, and outpatient clinics, and other organizational units of hospitals, units of production equipment and medical devices, units of the marketing and technical acceptance and accreditation and validation of equipment and medical devices, units of the design, construction and technological equipment and medical devices, scientific institutes of research and consulting, and health administration.

The first four terms of the undergraduate level involve general subjects, the same for all four-stream courses run within Biomedical Engineering. Assessment methods are defined in the ECTS system accessible by e-net [1]: Z - credits are awarded based on continuous assessment; E – credits are awarded based on continuous assessment and final exam; L – Lecture; T – Tutorials; Lab. – Laboratory; P – Project; S – Seminar. All data of the curricula are available at the ECTS info [2] or at the homepage of the BME [3].

It should be underlined, that students have full access to the electronic platform using the Moodle software, supporting education by delivery of all information concerning organization of study processes, including administration, and providing instructions of all laboratories, basic literature and software, as well as distance learning modules, which are applied in 18 subjects at the first level of education and 10 modules at the second MSc level. Student laboratories are very well equipped, too. Fig.1 shows the Laboratory of Medical Instrumentation as an example. There are also full capabilities for development of instrumentation during group and diploma projects, which often are related to research projects run in the departments involved in BME education. Fig. 2 shows one of results of such activities.

The subjects taught during common four semesters are:

- Linear Algebra
- Calculus 1and 2
- Chemistry
- Physics I and II
- Social Sciences for Engineers
- Elementary Mathematics
- Methods and Techniques in Programming
- Information Technologies
- Databases
- Material Science
- Programming Techniques
- Probabilistic Methods and Statistics
- Metrology
- Circuits and Signals

- Semiconductor Devices
- Biochemistry
- Biophysics
- Computer-Aided Design
- Basics of Automatic Control and Robotics
- Signal Processing
- Semiconductor Devices
- Electronic Circuits
- Biomaterials
- Electronic Medical Equipment
- Implants and Artificial Organs
- Mechanics and Strength of Materials
- Basics of Image Processing
- Legal and Ethical Aspects of Biomedical Engineering
- Propedeutics of Medicine
- Medical Imaging
- Sensors and Measurement Converters
- Physical Education
- Foreign language.

Fig. 1. Laboratory of Medical Instrumentation – USG as the most popular visualization modality. Fot. M. Kaczmarek.

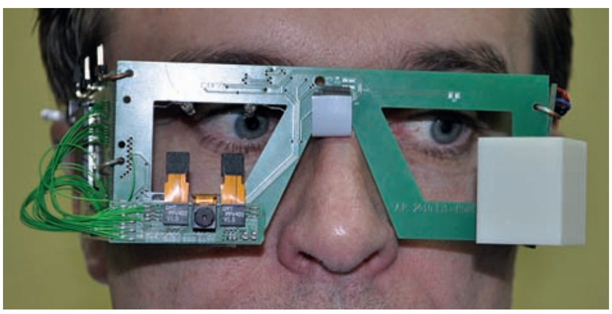

Fig. 2. The prototype of the multimedia eyeglasses (eye-tracking subsystem, front camera, microdisplay, Linux platform). Fot. M. Kaczmarek

This program fulfils all formal requirements for the ministerial minima as well as requirements for a clinical engineer.

As the undergraduate course is finished at the end of the winter semester there is a real challenge to organize all exams in the way allowing smooth recruitment to the second level of education. There are several practical problems, as e.g. proper number of candidates to open a specialization. Therefore also the first semester at the second level is of general scope, the same subjects for all specializations, to allow smooth admission to the second level of education and give some time for the decision on specialization. This semester contains the following subjects:

- Mathematics
- Random processes
- Numerical methods in modelling
- Modelling of biologic structures and processes
- Information systems in medicine
- Rehabilitation engineering
- Medical telematics
- Tissue and gene engineering.

The following two semesters are organized in a unique way. There are so called the main and the additional specializations. The content of main specializations is described in the following text. An additional specialization is just an offer of five courses in the main specialization but treated as elected subjects by individual students of other specializations. This way students may choose between four main specializations and have additionally flavour of one more, e.g. *Electronics in medicine* as the main specialization and five subjects taken as the additional elected material from *Physics in medicine*. Diploma is given as MSc in BME with the main specialization.

Chemistry in medicine

The purpose of creating the *Chemistry in medicine* course as one of four proposed streams in the multidisciplinary studies of Biomedical Engineering (BME) was to offer the students broad education in chemistry viewing its medical aspects and introducing the latest scientific achievements in medical analysis, diagnostics and therapy. That can only be possible with a good understanding of fundamentals of general and bioorganic chemistry, analytical and clinical chemistry. The courses dealing with material science, such as sensing materials and sensors, biocompatible materials of new generation for dental science or plastic surgery, miniaturization leading to nanotechnology, separation processes with the use of artificial membranes, synthetic conducting polymers playing the role of "organic metals" or working as artificial muscles. Our graduates should be capable to fully understand the interactions between some molecules and the big role it plays in biological processes as well as to find the application of the phenomena in some areas of medicine.

The first four terms of the undergraduate level of *Chemistry in medicine* involves general subjects, the same for all four-stream courses run within Biomedical Engineering as it was shown. After that, three-term period is dedicated to the course of choice, offering following lectures, tutorials, seminars or laboratories:

- Organic and bioorganic chemistry lectures & laboratory
- Medical chemistry lectures & tutorials
- Introduction to biotechnology lectures & laboratory

- Analytical chemistry lectures & tutorials & laboratory
- Biocompatible materials for special applications lectures & laboratory
- Physical chemistry lectures & tutorials
- Clinical analysis lectures & laboratory
- Nanotechnology lectures & laboratory
- Membrane processes lectures & laboratory
- Chemical sensors and sensing materials lectures & laboratory & project
- Conducting organic polymers lectures & laboratory & project

We intent that the course runs as interdisciplinary studies of Biomedical Engineering. It is a good solution for gaining broad and professional skills and knowledge. During the last term of undergraduate studies each student should complete a short project on a given topic from the chosen area of chemistry. Finishing and performing this task successfully will result in obtaining *engineering degree in BME – "Chemistry in medicine"*.

The second level, the graduate studies, lasts another 3 terms. The first term consist only of general education topics common for all stream courses of Biomedical Engineering as it was shown. The second and third term of "Chemistry in medicine" offer education on more advance level on following topics:

- Toxicology lectures
- Supramolecular chemistry & medicine lectures & project
- Introduction to molecular modelling lectures & project
- Elements of genetics lectures & tutorials & laboratory
- Biology of cancer cell lectures & tutorials
- Diagnostics in molecular medicine lectures & tutorials & laboratory
- Pharmacology lectures
- Introduction to environmental chemistry lectures & laboratory
- General microbiology lectures
- Thermodynamics of solutions lectures & tutorials

During the last two terms also will be the time for preparing research thesis in a chosen area of medical chemistry. At the end, the thesis has to be completed, all the exams should be passed including the final defence of the thesis and the students will get the degree of *Master of Science in BME, specialization ChM*.

That program shows the multidisciplinary character of the studies. The teaching is carried by specialists from versatile areas of chemistry but the basics are common for all four specializations.

Electronics in medicine

Electronics in medical applications is utilized in supporting diagnostics, therapeutic process, or to correct performance of human body parts or organs. Processes of data collection (measurements) and then signal processing are essential in all above mentioned applications. In practice, majority of medical electronic devices support or realize both tasks. It is the reason that the curriculum of *Electronics in medicine* (*EM*) stream contains these issues. In general, the realized curriculum of *EM* may be divided in a few thematic and essential blocks. Each of them contains lectures delivering basics and the background as well as a specific and detailed knowledge and skills.

Diagnostic procedures are basic for proper medical treatment. In turn, an essential part of these procedures are data collection (measurements) and then their processing which lead to gain of useful information. That why, the "metrological block" is an important part of the curriculum. It contains of the following lectures: *Metrology*, *Sensors and Transducers*, *Bio-measurements*, *Basics of Data Analysis*, *Methods of Experiment Designing*, *Interfaces of Data Acquisition Systems*, *Distributed Measurement Systems*, and the *Laboratory of Diagnostic Systems*. In fact, the following lectures: *Bio-signals*, *Signal Processing*, and *Backgrounds of Image Processing* may be also included to this block of issues.

The first lecture delivers information on specific properties of signals obtained by means of different methods and techniques from biological samples or from human body organs. In turn, the second and following lectures enable to master skills in application of digital processing methods as applied to signals, including signals gained from the human body. The third lecture constitutes an extension of the second one on two-dimensional or three-dimensional signals, i.e. images. Medical images have to fulfil special requirements resulting from their role in patient treatment. Hence, it is necessary to deliver knowledge on appropriate norms and standards dealing with medical images. The following lectures may be included to the same group: the *Laboratory of Diagnostic Systems*, *Methods of Planning Experiments*, *Interfaces of Acquisition Systems* and *Distributed Measurements Systems*. These lectures are giving the basic knowledge on principles of advanced measurements and analysis methods or techniques and are basic for improving skills in designing of measurement systems and devices using optimal data analysis procedures.

Students participating in *Biomedical Engineering* courses gain knowledge and develop skills in using medical electronic devices (the subject – *Medical Electronic Devices*) and in understanding of imaging techniques (*Techniques of Medical Imaging*) on the basic level but the lectures contain significant amount of topics with electronics background, too. As these lectures are delivered at higher semesters students already are familiar with basic electronics principles, ideas, elements and devices (lectures: *Circuits and Signals*, *Semiconductor Devices*, and *Basic Electronics*). All these lectures form the background for introducing classes devoted to design of medical devices (*Backgrounds of Medical Devices Design*). In fact, this subject is preceded by a similar one titled *Computer Aided Design*. However, the latter one is discussing basic problems, methods and tools used when designing electronic equipment in general. The main goal of *Backgrounds of Medical Devices Design* is to make students "sensitive" to specific requirements and problems arising when designing medical devices.

Students obtain knowledge and skills enabling them appropriate analysis and design of non-complex medical devices. In general, they learn about designing methods which provide the equipment with demanded properties, e.g. safety, serviceability, resistance to environmental conditions, fulfilment of ecological regulations, etc. Selected aspects of these issues are then extended during the courses of *Electromagnetic Compatibility of Medical Devices*.

Students are especially expected to develop skills in modern digital technologies including digital and programmable techniques. They are trained on using microprocessors, microcontrollers, and embedded systems and also on programming and simulation techniques attending the following subjects: *Basics of Digital Techniques*, *Modelling and Simulation Languages*, *Programmable Circuits*, *Microprocessors and Microcontrollers*, *Embedded Systems*, *Computer Systems Architecture*, and *Introduction to Computer Networks*. Programmable circuits are inherent and developing part of electronics, also this applied in medicine. It is the reason that this block of lectures is relatively big. To make education complete the students also are taught software skills, including usability of common languages (structural, procedural, object oriented or declarative). Aside programming languages (*Methods and Programming Techniques*, *Data Bases*) graduates of *Electronics in Medicine* stream possess skills of utilizing numerical, algorithmic, and simulations methods.

The lecture *Personal Assistive Devices* might be included to previously described lectures in the electronics block but it is discussed separately because it is considered as continuation of *Electronic Medical Devices* but also as an extension and a kind of recapitulation of skills possessed by students. Each student is expected to perform an individual design project. This demands of practical using of all types of skills trained during the study, i.e. metrological, designing and developing electronics circuits, both analogue and digital, programming and running the developed circuits and finally utilizing it in *in vivo* or *in vitro* experiments.

Comments concerning the second level of *EM* education are as it was discussed in the text of *Chemistry in medicine*. The list of subjects taught during the second and the third semesters contains:

- Ultrasounds in Medicine,
- Lasers and Optical Fibres in Medicine,
- Computer Aided Decision Systems,
- Interactive Graphics and 3D Visualization,
- Virtual Prototyping,
- Diagnostics and Prosthetics of Hearing and Vision,
- Biometry,
- Advances of Technology,
- Inverse Problems in Medicine and Biology.

The most important is an individual diploma project, when student should utilize all the theoretical as well as practical knowledge and skills to show he is prepared to get master degree in *Biomedical engineering* with the specialization *Electronics in medicine*.

Informatics in medicine

Informatics in medicine or *Health informatics* is a discipline at the intersection of human-related sciences (especially medicine) and computer science. It is a discipline, which is intensively developed in parallel with information technology and the latest developments in medicine and biology. Currently, the key areas in the field of health informatics are:

- Clinical informatics,
- Personal health informatics,
- Bioinformatics,
- Public health informatics, and
- Imaging informatics.

Offering *Informatics in medicine* course as one of the four proposed in the multidisciplinary study of Biomedical Engineering at Gdansk University of Technology main attention was focused on the issues leading from data acquisition to knowledge discovery and application. During the undergraduate study period, students gain knowledge of:

- data acquisition methods,
- data bases,
- computer networks and data exchange protocols,
- health informatics standards for data acquisition, storage, processing and visualization,
- programming languages for servers, desktop computers and portable devices,
- data analysis methods, including image reconstruction, processing and analysis,
- data mining and knowledge discovery methods,
- developing secure information systems (Internet and intranets),
- Information visualization.

Particular attention is paid to develop the skills and independent problem-solving ability to work in a team. Many of the subjects offered during the *Informatics in medicine* course offer individual or team projects, so students can apply knowledge in practical situation.

The first, undergraduate, level of *Informatics in medicine*, involves four terms of shared subjects and three terms focused on specialized subjects:

Related to systems and networks:

- Architectures of computer systems,
- Introduction to computer networks,
- Ethernet and IP networks,
- Microprocessors,
- Multimedia data exchange and storage,
- Data exchange protocols,
- Security of systems and services,
- Fundamentals of biometry,

Related to data analysis:

- Fundamentals of data analysis,
- Image reconstruction and analysis methods,
- Data warehouses and data mining,

Related to programming and information systems:

- Software engineering,
- Mark-up languages in healthcare,
- High level programming languages,
- Distributed processing,
- Application servers and web services,

Related to applications of informatics in healthcare:

- Development of internet applications in healthcare
- Telemedicine and mobile systems.

All subjects are divided into theoretical (lectures) and practical (laboratory exercises or projects) parts.

Students of *Informatics in medicine* have access to the most modern laboratories equipped with desktop computers (PC/Mac), servers, mobile devices, communication terminals, data acquisition equipment (e.g. 3D scanner), biometric equipment, and professional software. During the study period students use the same category of equipment and software as they can find in the future job.

Graduate will have knowledge and skills to ensure job in reputed IT companies, pursuing projects in medicine, bioinformatics, and security of citizens. They can also continue their education during graduate (MSc) studies.

The second level of education in *Informatics in medicine* takes 3 terms. Students will gain knowledge and skills during professional and modern subjects like Bioinformatics, Artificial Intelligence, Multimodal Visualization, and many others. They can also participate in the research projects in the Department of Biomedical Engineering doing their MSc thesis.

Physics in Medicine

The main purpose of creating the "*Physics in Medicine*" course as one of four proposed in the multidisciplinary studies of Biomedical Engineering at Gdansk University of Technology was to offer broad education in medical physics incorporating the latest scientific and professional findings in medical instruments, diagnostics and therapy. This can only be possible with a good understanding of fundamentals of atomic, molecular and nuclear physics. In particular radiation physics dealing with the principles of all kinds of radiation used in medicine is of a great importance to the graduates of this course. Our graduates should be capable to fully understand interactions between radiation and biological matter as well as to assess all hazards related to ionising radiation itself. At present, medical physicists working at hospitals are responsible for therapeutic beam diagnostics and quality assurance, treatment planning and positioning of the patient during the radiation treatment with external beams or internal radioactive sources. Our alumni may also design and control radiation installations for hospitals to ensure its proper functioning and monitor radiation hazards. In many research institutions medical physicists are involved in designing of new medical equipment expanding its applications and developing new imaging procedures. Such versatile specialists must also be capable of communicating both with physicians (Fundamentals of Imaging in Medicine, Radiobiology, Anatomy and Physiology) and technical staff (electronic engineers, IT specialists etc). We hope that the course program run as interdisciplinary studies of Biomedical Engineering at Gdansk University is a good solution of gaining such combined and professional skills.

The first, undergraduate, level of "Physics in Medicine", involves four terms of general subjects, common to all courses run within Biomedical Engineering, and three-term period dedicated to the course of choice, offering:

Basic education in general physics:

- "Physics in Biology and Medicine" – lectures and tutorials,
- "Calculus in Physics and Technique" – lectures and tutorials,
- "Mathematical Methods in Biophysics"– lectures and tutorials,
- "Physics laboratory" – laboratory
- "Fundamentals of Nanotechnology" – lectures and laboratory,
- "Generation and Detection of Radiation" – lectures,
- "Generation and Detection of Magnetic Fields" – lectures;

Thorough background in atomic and nuclear physics – lectures, tutorials and/or laboratories and projects:

- "Introduction to Atomic and Molecular Physics",
- "Physics of Atomic Nucleus and Elementary Particles",
- "Laboratory in Nuclear Physics",
- "Fundamentals of Spectroscopy"

These are followed by more detailed description of their wide-range applications in various fields of medicine and biology:

- "Nuclear Medicine and Radiotherapy",
- "Radiobiology and Radiation Protection",
- "Medical Imaging",
- "Particle Accelerators",
- "Introduction to Modelling in Biological Systems",
- "Lasers in Medicine",
- "Ultrasounds in Medicine".

The multidisciplinary character of the studies is reflected by the fact that teaching is performed by experts from diverse areas: experimental and theoretical physicists, physicians, electro- and acoustic-engineers.

During the 3-term period of undergraduate studies students have to complete the four-week-long training period, preferably in hospitals and centres of diagnostic and therapy. The first group of students of "Physics in Medicine" in the year 2011 served their training at the Gdansk University of Medicine in the Laboratory of Radiology Oncology in Gdansk and in the National Centre of Hyperbaric Medicine in Gdynia.

During the last term of undergraduate studies, a short project has to be completed by each student. Succeeding in performing this task results in obtaining and engineering degree in BME, specialization "*Physics in Medicine*"

The second level of education – graduate studies – takes 3 terms. The first term covers the range of general education subjects, common for all the courses of Biomedical Engineering. In the second and third term the studies of "*Physics in Medicine*" offer more detailed insight into issues described during the first level studies:

- "Molecular Physics",
- "Optical Spectroscopy in Medicine",
- "Nanotechnology in Medicine"
- "Collision Spectroscopy",
- "Detectors of Radiation",
- "Computer Tomography",
- "Acoustic Methods in Medicine".

During the 2nd and 3rd term also a research thesis in a relevant area of medical physics has to be completed, and passing of all the exams including the final defence will be honoured by the degree of Master of Science in BME, with specialization of MPh.

The presented programme is meeting all requirements necessary to get the job as *Medical Physicist*; only additionally practical placement in a hospital is required, according to legal regulations.

Biomedical Engineering as interfaculty direction of study – challenges and problems

We have been strongly involved in all processes related to preparation of GUT for education of BME as interdisciplinary courses, being present in all formal bodies working on and supporting the idea of revitalization the BME direction of study in Poland. Unfortunately the beginning of running this direction of study at GUT was delayed, comparing to our partners, AGH and PW, due to internal opposition and hesitation if this study would be cost effective. Also some key persons in university administration have been probably worrying how the admission to the new BME course will influence number of candidates for other directions of study. Fortunately positive decision of the Ministry concerning the POKL project finished all hesitations. Besides these very early discussions today we may proudly declare that admission of BME students was very positive in terms of the number of candidates decided to apply to GUT. Also the cross-section of the candidates made the palette of students much more "colourful". The most of candidates are girls, around 70%, what strongly improves the number of studying women at the WETI faculty. The change of proportion of man to woman is today clearly visible, in one word – our premises are brighter and more beautiful. Also early questions if the candidates will be competitive enough comparing to others at the WETI are definitely positively cleared up, as those who asked such questions are coming today with extremely good opinions on quality, ambition and competitiveness of BME students.

One has to admit that a broad and extensive promotional action was preceding all calls for candidates of BME study. We applied all possible means of informing public what is the BME direction, where are potential work places, how important and of what international value is the future of this field of science and engineering. Not only paper leaflets but also some promotional movies, slide presentations etc. have been prepared with important participation of our graduate and PhD students. One of more important is the event called Science Festival, organized this year in May. Almost one thousand young people participated in shows and presentations related to BME. In effect the interest of young candidates for study BME was really impressive till now. The total number of accepted candidates for study BME is limited every year to around one hundred. The number of candidates for BME per one place was from around 3 to 6, depending on the year.

The statistics based on the study effects shows that the students of Biomedical Engineering TUG have got this year the highest mean results among all directions of study run at the WETI faculty, after all three winter semesters, where we have BME – at the first, the third and the fifth semester. Also opinion of students concerning academic staff was in average highest for the teachers of BME. Those so satisfying results are due to very high mobilization of students and their ambition, but also due to special care of the staff. Having extra funds and resources from the POKL project additional equalization lectures of mathematics and physics are offered at the second semester, attended by almost all of the students. The coming year we will prepare also such help at the first semester for Chemistry and Physics.

We are proud that preparation of educational infrastructure for BME is extraordinary. Almost all taught subjects are supported: laboratories are modernized, finally 300 upgraded or new hardware and software laboratory exercises are expected to be worked up during the POKL project realization period. Here not only POKL but also several other projects are implementing in purchase of modern equipment. Around 100 lectures of the first and the second levels of education already are or will be supported by electronic versions of syllabuses as well as electronic handbooks; all available at the electronic platform which is regularly updated. High quality of educational material is assured by introducing high norms of quality control. We share also experience with our partners AGH and PW. There are meetings and courses organized allowing discussions on education methods and materials. All activities are carefully analysed, monitored and upgraded. Also very important are conclusions possible due to cooperation with hospitals and medical equipment companies, both national as foreign, too. Special efforts are directed to organization of student mobility and practical placements.

Students have possibility for participation in many research projects run by the departments involved in the POKL project. Fig. 3 shows an example of prototyping of a final product – the remote control for elderly and disabled people, developed in the DOMESTIC project [5]. One may see the 3-D printer for prototyping mechanical parts of the instrument; additionally at the upper right part there is a special ASIC developed for the purpose of the project (produced by the Europractice), and bottom-right is the operating product.

Fig. 3. Illustration of our complex approach to project development: a personal „pilot" – the remote control panel, for operating audio-video instrumentation, with monitoring such vital signs as ECG, pulse, SaO2, but also the strength of the palm muscles as well as signaling of requested actions, e.g. "take a pill". Fot. M. Kaczmarek.

Very important are efforts directed to make attractive educational material as well as lectures – special programme to introduce distant learning modules and tools for at least 28 subjects are at the development phase. This task unfortunately is not easy, as preparation of proper material requires special mobilization of teachers, who are not necessary specialists in such modern educational tools. Therefore additional courses for staff and students devoted to distance learning are organized each year, so we believe that this effort will improve motivations of students and will have positive impact on quality of education. Finally some international exchange of teachers is assured allowing formation of high professional staff.

We already finished 3 years of the first level education – six full semesters. Also the final semester is already organized and prepared logistically. All students of the final year know their engineering projects for more than 3 months. Some are already advanced in preparation of the diploma project.

Looking to all the results we have already achieved but also having in mind challenges of the educational market and threads which are still in front of our plans we are optimistic. The future of medical technology development and practical use not only in Poland will be in hands of our present students!

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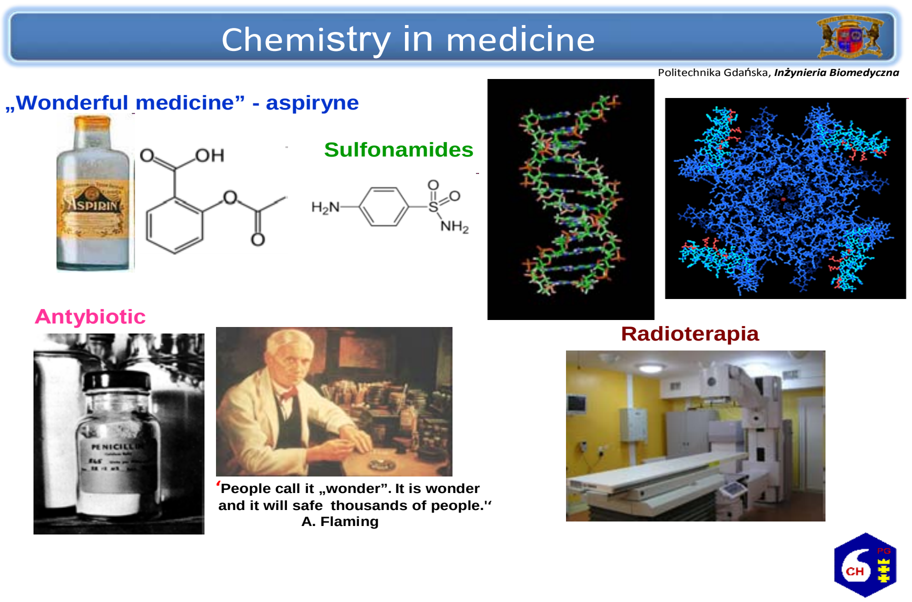

KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI

UNIA EUROPEJSKA
EUROPEJSKI FUNDUSZ SPOŁECZNY

Projekt *„Przygotowanie i realizacja kierunku inżynieria biomedyczna – studia międzywydziałowe”*
współfinansowany ze środków Unii Europejskiej w ramach Europejskiego Funduszu Społecznego.
Nr umowy UDA – POKL.04.01.01-00-236/08

BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 67-72

BIOMEDICAL ENGINEERING EDUCATION AT THE WARSAW UNIVERSITY OF TECHNOLOGY

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Abstract: Education on medical electroengineering at the Warsaw University of Technology (WUT) was introduced in 1946. Recently, WUT was among the institutions which initiated introduction of Biomedical Engineering education to Polish universities as complete study curriculum. Inter-faculty studies in Biomedical Engineering at the Faculty of Electronics and Information Technology and Faculty of Mechatronics started in 2007. Education at two levels is provided – engineer/BSc (7 semesters) and MSc (3 semesters). The curricula comply with Polish national educational standards, Bologna Declaration and indications of the International Federation for Medical and Biological Engineering (IFMBE). The graduated specialists are expected to be prepared to activities in several fields of biomedical engineering profession.
Keywords: biomedical engineering, education

1. The importance of Biomedical Engineering

Improving the quality of health care increasingly involves the use in clinical practice, the achievements of other scientific disciplines – both fundamental, like mathematics, physics, chemistry, and applied engineering knowledge. On the other hand, one of the key drivers of technological progress are the medical applications. Implementation and application of new medical techniques require a joint effort of research institutes, industry, healthcare facilities and health administration.

Biomedical Engineering education in Poland has good and long tradition. It was introduced as a specialization of medical electro-engineering in 1946 at Electrical Engineering Faculty of the Warsaw University of Technology. Now Biomedical Engineering is one of the newest interfaculty fields of education at the Warsaw University of Technology (WUT). This is an interdisciplinary field of study, carried out jointly by the Faculties: of Electronics and Information Technology and of Mechatronics. Biomedical Engineering students are trained in the field of automation and robotics, chemistry, electronics, computer science, biomaterials engineering, mechanics, and simultaneously learn the basics of biomedical sciences. Graduates of this course gain a thorough knowledge in the field of basic technical education, as well as specialization subjects. Thus, the scope of their powers authorize them to cooperate with medical staff and to solve technical problems that require understanding the specific needs of the broadly understood health care.

It is expected that due to the growing importance of health care, biomedical engineers will be much-desired on the labor market in the nearest future. With the ability to use knowledge from several disciplines of engineering, Biomedical Engineering graduates may undertake work not only in research institutions and public and private health-care centers, but also in industry connected with health care needs, including small businesses.

In hospitals, clinical units, outpatient treatment and other organizational units of treatment, biomedical engineers can cooperate with medical doctors in the area of integration, operation and maintenance of medical equipment and servicing diagnostic and therapeutic systems. Graduates can also be employed as designers and engineers in factories of medical devices. They should also awake interest of institutes conducting scientific research on biomedical engineering, both basic and applied, as well as development, implementation and design works. Moreover, the knowledge and skills acquired during studying Biomedical Engineering can be taken as an advantage in the units of trade turnover and technical acceptance. It can also be used in the process of accreditation and attestation of medical equipment, as well as in consulting firms and health administration.

2. Biomedical Engineering as a field of study at the Warsaw University of Technology

2.1. First degree (B.Sc.)

Biomedical Engineering is formally conducted by two Faculties of Warsaw University of Technology: The Faculty of Electronics and Information Technology and the Faculty of Mechatronics. The training program is primarily determined by governmental standards and the resolutions of the Senate of Warsaw University of Technology, which determine the number of teaching hours for technical fields of studies in such disciplines as mathematics, physics, the arts and economics, foreign language and physical education. Education includes learning for 7 semesters, with the possibility of prolongation for the next two. We managed to establish the same program of undergraduate degree (engineering) for both faculties, carried out jointly, in one group of students, for both faculties. And so, the first four semesters of study include mainly acquiring knowledge of a fundamental nature which is later complemented by more specialized material (semesters 5-7). At the final stage of study the pressure is put on deeper, more specialized education and on the diploma project. Training at this stage is done under the supervision of an individual tutor, who is also a promoter of an engineering work. Previous experience shows that students prefer to choose for promoters lecturers from their faculty, however about 20% selected tutors are from the outside – specialists in the area of a particular student's interest, such as e.g. material engineering.

Engineering knowledge, integrating many technical specialties, is developed on the basis of a common standard of basic subjects: mathematics, physics, chemistry, mechanics, material science, electrical engineering and electronics.

Students learn how to apply mathematical methods to describe the technical issues. Lectures cover the basic concepts of linear algebra, integral calculus, elements of differential calculus, numerical series, Fourier series, basic information about the functions of a complex variable, integral transformation. In addition, they get familiar with the possible applications of the theory of probability and mathematical statistics in biological and medical research.

By participating in the classes of physics, students gain the abilities to perform measurements of fundamental physical quantities, the analysis of physical phenomena and solving technical issues on the basis of the laws of physics. They acquaint themselves with the basics of classical mechanics, electrodynamics and optics to the extent typical for technical universities, with particular emphasis on the needs of Biomedical Engineering. Subsequently fundamentals of physics are taught in the field of quantum mechanics and statistical physics. Particular attention is paid to issues of measurements in physics, within which students have the opportunity to work in well-equipped laboratory.

Chemistry classes teach the understanding of chemical transformations and their importance for industrial processes. The purpose of education in this area is to present construction and transformation of matter at the micro-and macroscopic level, with particular emphasis on the theory of chemical bonds. Students learn the classification of elements and chemical compounds, as well as the most important types of chemical bonds in molecules, and intermolecular interactions in macroscopic systems. The lecture covers the morphology of chemical reactions and transformation of matter. They also provide an overview of the structures, properties and methods of preparation of selected elements and their major compounds. Here again students acquire practical knowledge in the laboratory of organic and inorganic chemistry.

In terms of mechanics and strength of materials, special attention is focused on solving technical problems, based on the laws of mechanics and strength analysis of particular components of mechanic device.

In the case of materials science, students learn about the major issues concerning the materials, the related terminology and the principles of selection of materials for biomedical applications in terms of shaping their structure and properties. Laboratory classes provide an opportunity to measure several physical parameters of materials, deciding on their usefulness in medicine and biology.

The program in Electrical Engineering covers the basic methods of analysis of electrical circuits. In particular, the methods of analysis of direct and periodic current circuits, with an emphasis on sinusoidal current systems. There are also presented basic methods of analysis of nonlinear circuits and resonant circuits as well as elementary electrical systems designs. Moreover, there are also analyzed three-phase circuits and the characteristics of the real components of electrical circuits.

Fundamentals of Electronics include principles of operation and the most important parameters of basic semiconductor devices and structures, working principles and methods of analysis of simple analog and digital circuits. In the laboratory practical classes, students have the chance to see, examine and measure the parameters discussed in the lectures of electrical engineering and electronics systems.

Fundamentals of engineering are complemented by preparatory instruction of medical sciences. These are: Basics of human anatomy and physiology, the construction and functioning of cells and tissues, structure, physiology and functioning of human systems: musculoskeletal, nervous, digestive, respiratory, circulatory, urogenital. Goals of medicine are formulated, as well as definitions of health and disease. Lectures include a division of medicine according to the criteria of clinical medicine, medical specialties, the organization of health care. Other topics taken into consideration are: diagnosis; ways and criteria for drug dosage, hemodialysis, surgical treatment, endoscopic operations; ways of counteracting pain, haemorrhage and infections, local and general anaesthesia, antisepsis and asepsis, dressing wounds, grafting implants, tissue and organ transplants, intensive care, resuscitation with the use a defibrillator, respirator, pacemaker, iatrogenic injuries.

Another group of issues discussed are: health care management, legal regulations for medical devices, issues of electrical, mechanical and radiation risks; legal aspects of the operation of clinics, supply systems, cost analysis, quality control systems, accreditation of laboratories; ethical problems in the health care system, ethical and legal conditions associated with transplantation and genetic engineering, the procedures for obtaining certificates for medical materials and equipment and licenses to clinical research, norms and standards in force in biomedical engineering. The contents of a basic education are completed by subjects providing practical skills in computer operation.

At the beginning, students gain the practical skills equivalent to ECDL certificate in basic information technology, computers construction, their operation principles, basic data communication networks, industrial safety and use of basic ICT tools in the form of office packages, Web browsers and e-mail.

In terms of programming, students learn the principles of program development in structural and object-oriented languages. Structural languages are discussed on the example of C language and object-oriented languages on the example of C++ language. This includes the rules of structured programming, the division of code into functions, the syntex of the C language structures, unions and pointers of complex types. The objective is gaining the ability to abstract problems and write in C language. The paradigms of object-oriented programming are presented encapsulation, polymorphism and inheritance, the syntax of C++, references, redefining functions, constructors and destructors, virtual functions and templates.

In addition, techniques of computerized image processing are discussed separately: processing of real images into digital form, creating color images, methods of improving the quality of digital images, image acquisition devices. There are also discussed such issues as: psychology of media message, animation and virtual reality, mathematical foundations of three-dimensional computer graphics, realism in computer graphics, illumination models, texture (Fig. 1).

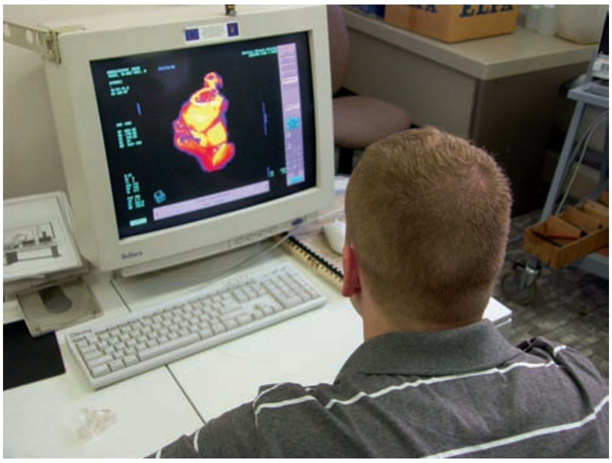

Fig. 1. Computer Tomography Laboratory at the Faculty of Electronics and Information Technology.

Finally, as far as the abilities to use computer-aided software engineering design is concerned, students explore methods of construction record, principles of representation and dimensioning projection, reduction, simplification in the geometric form and record of dimension system, fundamentals of finite element method (FEM) and boundary element method (BEM); selected numerical optimization methods, CAD / CAM systems. Students acquire certain skills, such as: reading assembly drawings, the use of FEM and BEM in assisting computer design, use of computer graphics in creating technical documentation.

Students are prepared for laboratory work (Fig.2), and introduced to the techniques of the experiment. They master the basic techniques of measurement, methods of error analysis and its reduction. In the laboratory they individually perform basic experiments in the field of signal and components. They learn the operating principles and characteristics of measurement tools and carry out the measurements of current, voltage, power, frequency, phase shift, resistance, impedance, measurement of non-electrical quantities with the use of electric methods. They are also acquainted with the basics of laminar metrology.

The specialized training program includes compulsory directional subjects and technical elective subjects. Directional education includes the following subjects:

- Sensors and measurements of non-electrical quantities
- Biochemistry
- Biophysics
- Radiology
- Signals and systems
- Fundamentals of Automatic Control
- Basics of medical imaging
- Numerical methods
- Elektronics 2 (specialised, medical)
- Rudiments of Robotics
- Biomaterials
- Electromedical devices
- Elektromedical devices for diagnosis, supervision, therapy and support
- Biomechanics for engineers
- Medical implants and artificial organs
- Digital image processing

The vast majority of specialized subjects listed above include practical classes, in addition to lectures. These are mainly laboratories, but also projects (higher semesters) and accounting practice. At the semesters from fifth to seventh students can choose as many as 25 teaching units (9-10 subjects) from a large number of technical elective subjects. Among them are subjects deepening their current knowledge, as well as subjects of entirely new areas and subjects perfecting students practical skills, useful in the implementation of the thesis. This group covers 16 subjects:

- Biometric identification
- Detection of ionizing radiation
- Evolutionary algorithms
- Data acquisition and processing in the LABVIEW environment
- Physics of the brain (electrophysiological brain phenomena)
- Logical programmable systems
- Introduction to MATLAB programming
- Finite Element Method and its applications In bioengineering
- Engineering Fundamentals of image diagnosis In medicine
- Basics of modeling In medicine
- Biomedical signals processing
- Neural networks in biomedicine
- Tomographic techniques
- Laser techniques In biomedicine (Biophotonics)
- Nuclear medicine techniques
- Ultrasound techniques In medical diagnosis

Fig. 2. Laboratories of Ultrasound Techniques, Nuclear Medicine and Electromedical Devices.

2.2. Second degree (M.Sc. studies)

The assumption of the second degree studies is to pass more abstract content. At this level the emphasis is put on both the deepening of general knowledge (in the advanced subjects of a general nature), as well as the development of problem-solving skills. Among the methods of education in-depth analysis of specific technical problems and searching for solutions play an important role. Master's Degree Program comprises 4 semesters, however graduates of Biomedical Engineering and related fields of study have the possibility to graduate after 3 semesters.

According to the current education standards, the second degree studies graduates possess advanced knowledge of computer science and electronics, medical telematics, medical materials, biomechanics, modeling biological structures and physiological processes and techniques of medical imaging. Graduate has certain skills: formulating biomedical engineering problems, solving them through modeling, design, development and construction technology using computer techniques, processing and transmitting information; managing teams of creative activity, taking creative initiative and decision making. Graduates are prepared to work in a creative environment where technical sciences support medicine: the use of modern data communication networks techniques, biomechanics, medical devices, grafting implants and artificial organs, solving research- and innovation-oriented problems, implementation of new solutions and taking doctoral studies (PhD).

Due to the small number of Biomedical Engineering graduates, who have obtained a degree in engineering and decided to continue their studies at masters degree, both recruiting faculties (Electronics and Information Technology and Mechatronics) decided to implement jointly only the program of study resulting from the standard of education at the ministerial direction, while the range of elective subjects is separate and shared with related specialties in other fields conducted within each faculty separately. And so common subjects are:

- Physical rehabilitation engineering
- Genetic and tissue engineering
- Methods of materials and tissue examination
- Analysis and modeling of physiological processes
- Computer systems In medicine
- Telemedical systems

These subjects are mandatory and include 19 ECTS (15 teaching units)

At the Faculty of Electronics and Information Technology, in addition to subjects related to the diploma, students have a choice of advanced subjects, grouped together in specially created for this field of study curriculum. It includes subjects allowing the development of their interest in various fields, particularly to assist in the implementation of the thesis. These are:

- Digital image processing
- Computer-aided dogital medical diagnosis
- Bioinformatyka
- Modeling In biomechanics

- Nanotechnologies
- Radiotherapy
- Electromagnetic resonance-based tomography
- High performance computing measurement methods in molecular biology

Students should choose at least three subjects from the list offered. Besides they choose 5-6 advanced subjects from the group of generally available subjects (more than one hundred subjects). This system has proven itself at the Faculty of Electronics and Information

Technology in the case of other fields and specialties.

With increasing number of students (enrollment has been so far carried out only for a single year of engineering graduates) there will be an opportunity to use recently adopted Law, "Law on Higher Education" and the opinion of the interested parties and make corrections in both the engineering and master degree program.

3. The specificity of studying Biomedical Engineering at the Warsaw University of Technology

Warsaw University of Technology is not the only university currently offering a degree in Biomedical Engineering. The first university, that launched this field of study was University of Science and Technology in Cracow in 2006, a year later Warsaw University of Technology and Silesian University of Technology opened this field of study. Now it is offered in different forms by several universities – both universities and technical universities. Despite the common name, the training programs at these universities are quite varied, depending on the competence and areas of interest of the academic staff. These differences should be taken into consideration when deciding to choose one of the universities.

There are several important reasons to choose Warsaw University of Technology as an University experienced in the education of engineers for the needs of medicine. Here they are:

- Warsaw University of Technology in the rankings consistently occupies first place among the technical universities, and is assessed by employers as dominant among all universities. This guarantees a high level of study, and finding interesting and satisfactory work.
- Although the BE course at our university was founded only two years ago, the tradition of education in the field of medical technology at Warsaw University of Technology has a long and rich tradition. In 1946, Warsaw University of Technology, as probably the first university in the world, started training in a field related to medical technology by opening the Department of Electrical Engineering in Medicine, in order to train staff for the reborn after the war, health care system. Education in the fields related to Biomedical Engineering has since been conducted continuously, despite the dynamic changes in the structure of the university. In 1970 The Faculty of Electronics and Information Technology and the Faculty of Mechatronics became leaders in research and teaching in the field of Biomedical Engineering. Before launching BE at WUT, the Faculty of Electronics and Information Technology, carried on (and still does) specialization in Electronics and Computer Science in Medicine (on the macro-field Electronics, IT and Telecommunications), while the Faculty of Mechatronics conducted a specialization of Biocybernetics and Biomedical Engineering at the Automation and Robotics field of study. There is also a specialization of Electromedical Equipment in the field of Mechatronics. Thanks to that WUT has not only excellent staff, recognized in the field of Biomedical Engineering, with the rich scientific achievements, but also many years of experience in education in this area of knowledge.
- Although formally the field of study of Biomedical Engineering is run by two faculties, the education process involves also employees of other Departments, including: Physics, Mathematics and Information Science, Chemistry and Materials Science. The result is that the spectrum of competence of lecturers is extremely broad. Programs of study are developed in accordance with the requirements and international orders [1] (Bologna Declaration, the recommendations of the International Federation for Medical and Biological Engineering – IFMBE) and national standards (recommendations of the Ministry of Science and Higher Education and the Council of Higher Education).
- Faculties have a very rich laboratory base, what is of a particular importance for technical studies. Students have to their disposal medical imaging systems for X-ray tomography (two units), for magnetic resonance tomography and SPECT emission tomography, X-ray apparatus equipment for ultrasound imaging, electrocardiography, reography and thermal imaging, equipment for computer-based analysis of microscopic images and more.
- Employees of both the leading faculties run a wide cooperation with many Polish and international medical centers, research and industry institutions associated with medical technology. This gives the opportunity to conduct thesis in interdisciplinary groups, interesting practical training and foreign exchange.
- Both faculties are active in the area of student scientific circles, where the students have the opportunity to deeper their knowledge by conducting the research projects, building a prototype medical equipment, or creating specialized software. These are: are: Scientific circle of Biomedical and Nuclear Engineering, Scientific circle of Techniques in Medicine and Scientific circle of Cybernetics (The Faculty of Electronics and Information Technology). The Faculty of Mechatronics has two circle: Scientific circle of Biocybernetics and Biomedical Engineering and Scientific circle of Biomedical Equipment.
- The Faculty of Mechatronics has the full academic rights in the discipline of Biocybernetics and Biomedical Engineering, so there is a possibility for further study (third degree) within the doctoral studies, and to obtain doctoral and post-doctoral degrees.
- The Faculty of Mechatronics is preparing postgraduate specialization in the field of medical engineering. Such studies would entitle graduates to work as clinical engineers in the institutions of health care (according to the Decree of the Minister of Health from 30.09.2002 with later amendments

on obtaining the title of specialist in the fields applicable in health care) .

There is also a number of other reasons to choose WUT, slightly more distant from the issues strictly related to studying, but probably equally important for young people.

– Warsaw University of Technology offers many opportunities for the realization of students' interests such as sports – in the AZS sections of Warsaw University of Technology or the Yacht Club, artistic – such as the Academic Choir, Theatre, Song and Dance Ensemble, and the music band "The Engineers Band". Student Sport and Tourism Committee supports various forms of sports activities and tourism, such as organizing rallies, canoeing, expeditions to remote corners of the world, cruises, etc. It also takes care of a student hostel "Koliba" – beautifully situated in the Bieszczady mountains, and built by students. Students have a chance to join in the activities of student media – i.pewu magazine, web portal Polibuda.info, Radio Active, and Student Internet Television. They have to their dispoasal also the legendary club "Stodola", as well as smaller faculty clubs – "Amplitron" at the Faculty of Electronics and Information Technology and "Mechanic" at the Faculty of Mechatronics.
– Studying in Warsaw itself has many advantages. First of all, capital is a huge and wide open labor market. Thanks that our graduates can easily find employment, often even before graduation. Saturation of the city with various companies also gives a chance to find an interesting place to hold a student internship.
– Warsaw, full of cinemas, theaters, galleries, museums, sports centers, clubs, pubs, restaurants, offers unlimited possibilities to realize your passions and spend your free time.

4. Summary

– Introduction to Biomedical Engineering education stems directly from the needs and stimulates progress in medicine.
– Education programs developed in the Warsaw University of Technology are modern, flexible and in accordance with global tendencies.

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BIO-ALGORITHMS AND MED-SYSTEMS
JOURNAL EDITED BY JAGIELLONIAN UNIVERSITY – MEDICAL COLLEGE
Vol. 7, No. 3, 2011, pp. 73-84

ADAPTIVE APPROACH TO BME TEACHING AT THE AGH-UST

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Abstract: This paper presents the general idea of adaptive mechanisms and their implementation in teaching of biomedical engineering in AGH University of Science and Technology in Krakow. The adaptation, initially implied by the novelty of profession and multidisciplinary character of the domain, revealed its advantages in striving for a quality education that considers multiple external and internal benchmarks. The paper discloses the organizational conditions of teachnig of a new discipline together with the management rules of the Multidisciplinary School and a general layout of the educational offer. Afterwards, aspects selected as instrumental in quality teaching are presented: building of international relations, education of practical skills and quality control mechanisms. Last chapter reveals advantages of teaching adaptation for competitive graduates in both aspects: general (concerning the study programme) and individual (concerning personal career building). The paper concludes by preliminary results estimating how MSIB students are evaluated in various internal and external circumstances. These results show that last year students and very first graduates not only show high level of professional knowledge, skills and competences, but also are self-aware enough to responsibly plan and manage their future careers.
Keywords: BME-education, quality teaching, learning organization,

1. Introduction

Despite long tradition of biomedical engineering (BME) and medical physics (MP) in Poland dating back to 1930 [1], until the academic year 2005/2006, education in biomedical engineering was systematically offered only as a specialization within other disciplines of studies, e.g. mechanical, electrical or tissue engineering. Consequently, professionals working today for technical support of health care identify themselves rather with their acquired craft names and 'biomedical engineer' seems to be a new term in educational offers of Polish universities. On the other hand, considering a notable contribution of BME research performed in Poland and the number of involved scientists (estimated for over 2500 people) it is clear that systematic education in this area is not only motivated by examples from abroad and new achievements of health care technology, but also results from high human potential and strong internal need of a middle-populated country for active participation in the progress of well being. Numerous examples from automotive or electronics industry indicate that Poland, besides being a final consumer of products, is also as an attractive region for manufacturing and in case of many enterprises even a base for research and development departments. This scenario could not be imagined for medicine-related technologies without a serious involvement from academic quality teaching.

1.1. The local conditions for BME teaching

Launching a new teaching discipline we had to consider not only the example of most developed countries, but also local conditions for education and employment for future graduates [2]. These initial external conditions can be classified into three groups:

– referred to Polish medical technology-related enterprises and institutions (poor condition of local enterprises, weak relation between research and industry and weak technological level of the health care)
– related to needs for the development of medical technology in order to adapt the quality of social health services in Poland to the standards of highly developed EU countries,
– related to Polish university traditions and traditional models of teaching (experience in teaching, growing interest in medical technology from good candidates, Bologna Process, international students mobility, innovative organizational chart and corporate culture [3] of a multidisciplinary school.

All the above issues and challenges led to stronger inter-university cooperation (some of them formalized as educational projects) and integration into the society.

BME teaching also subjects legal regulations specified by Polish Ministry of Science and Higher Education for general conditions of organizing study tracks in public universities, for description of learning outcomes (i.e. European Qualification Frameworks), students achievements (i.e. European Credit Transfer System) and for a specific domain of biomedical engineering (firs issued in June 2006 as Standard No. 49). The Standard, elaborated in years 2004-2006 with a significant contribution from representatives of AGH-UST, defines ca. 40% of the education programme as mandatory for all universities leaving the rest for their specific approaches.

Current employment perspectives mostly result from the growing importance of extensive use of technology in health care. Clinical engineer, equipment manufacturing engineer, researcher and sales representative are four main directions of specializations in building of future professional careers. Nevertheless, local employment markets are weak, and the effort to raise the awareness of a new profession to a higher level is continuously among the principal concerns of the MSIB management. In the academic year 2010-2011, BME education is being offered by 16 technical universities in Poland [4], although general statistics are favorable for the AGH-UST graduates: 75% of them find their first job within one month after graduation, and 95% within three months. According to other surveys, in 500 of Poland's biggest enterprises, AGH-UST graduates constitute the second largest percentage among senior management staff.

1.2. Management of competences without moving people

Due to longstanding experience and international contacts, the BME-related research competence list of the AGH-UST staff is fairly long. Mentioning only main areas of interest it includes:

- Artificial intelligence in image and signals interpretation (e.g. Medical images acquisition, processing, segmentation, analysis and automatic classification and recognition, Pathological speech analysis, classification and recognition for diagnostic, therapeutic ad rehabilitation monitoring purposes),
- Biomechanics, bioengineering, biotribology, biorheology (e.g. Identification and modeling of joints structures in the aspect of biomechanics. Mechanical engineering of biomaterials. Application of biomaterials in orthopedics and dentistry. Mechanism of lubrication of hip joint in the aspect of degenerative joint disease.),
- Biomedical imaging and modeling (e.g. Nuclear magnetic resonance imaging, Optical imaging, Modeling of physiological processes, Nuclear medicine diagnostic imaging and Quality Assurance procedures.),
- Materials science and engineering (e.g. Composite materials, Fracture mechanism, Biomaterials: Polymer-ceramic systems for medical application, Biomechanical aspect of biomaterials, Modification of resorbable polymers, Designing and manufacturing biomimetic composite materials.),
- Medical devices development (e.g. Adaptive wearable recorder for cardiology, Multimodal surveillance system for assisted living, Perceptual compression of electrocardiogram, Thermal prosthesis for the blind, Control system for disabled based on eye and brain signals.),
- Tissue engineering and biomaterials (e.g. Biocompatibility of carbon nanoparticles with tissues of the neuromuscular system, Polymers-based nanocomposites with magnetite and carbon nanotubes Membrane implants for deep sclerectomy Bioresorbable implants for nerve guide Bioresorbable scaffolds for bone and cartilage tissue engineering Bioresorbable membranes for guided tissue regeneration in periodontology.).

In aspect of striving for a widest possible education offer, the optimal approach should involve all the leading researchers into the educational process. Unfortunately, those people had well established positions in separate departments and institutes of our University, having also developed research infrastructure and adequate human resources. Therefore, without doubts about their goodwill towards a horizontal cooperation, it would not be reasonable to expect them to move to a new organizational structure. Considering additionally the urgent need for launching a new BME educational offer, the Rector of AGH-UST prof. Ryszard Tadeusiewicz decided to found the Multidisciplinary School of engineering In Biomedicine (MSIB) as a separate unit of the University with the principal mission of BME education without the institutional constraints.

2. Organizational details of BME teaching

2.1 The organizational scheme of MSIB

Formally, MSIB's structure is similar to that of other faculties [5]. It is governed by a Programme Board (currently composed of 18 persons) having all decisive privileges concerning the teaching directions, contents and methods. This Board, personally approved by the University Senate, is made up of professors with not less than a DSc degree who are teaching at MSIB, as well as of an adequate representation of students. At present, the professors represent five faculties:

- Faculty of Electrical Engineering, Automatics, Computer Science and Electronics,
- Faculty of Materials Science and Ceramics,
- Faculty of Mechanical Engineering and Robotics,
- Faculty of Metals Engineering and Industrial Computer Science, and
- Faculty of Physics and Applied Computer Science.

One of the Board's tasks is to recommend to the Rector appointments for the Head and the Deputy Head of the School. The appointee Head is also President of the Board. The main responsibility of the Board is to supervise the educational process, assure its highest quality, verify and, if necessary, correct academic curricula, prepare staff assignments and implement other objectives of the School. The Head also represents the MSIB in the University Board on par with deans of other faculties. Other duties of the Head include making individual decisions concerning atypical students' cases, organizing events with the contribution of the School (e.g. conferences or public presentations), creating and executing the identification and information policies, creating relations with industrial and health care partners, representing the School in international projects and relations etc. The Head is responsible for the execution and completeness of the educational process, for correctness of its financial background and for the staff related to the education area. The Deputy Head of the School is primarily charged with social support for disadvantaged students.

Besides the Board, the School is supported by two permanent workers of Dean's Office (having student's affaires, financial details and administration in their duties), and by other university workers delegated by supporting faculties contributing with their specific roles:

- students mobility coordinator (e.g. Erasmus),
- industrial trainings coordinator and supervisor,
- recruitment commission supervisor,
- teaching quality inspector,
- distant learning platform administrator,
- information technology and confidential data manager.

The duties and rewards of each particular person are subject of agreement between the Head of the School and the dean of employing faculty.

2.2. Place of the School in University structure

The MSIB is located at the AGH University of Science and Technology and has been in operation since the academic year 2005-2006. This favorites the position of BME teaching in the university structure as if MSIB were a separate regular faculty. Moreover, the organizational formula different from other faculties expresses a particular attention the Authorities of AGH University of Science and Technology pay to this education area. Other advantage of the autonomy lies in independent design and implementation of a BME-specific organizational culture with distinct ceremonies, values, common meanings and purposely designed management rules. It is worth to stress, that some recent solutions (e.g. engineer diploma examination) were first implemented in limited scale by MSIB and in following year adopted by other departments of the AGH-UST.

From the student's viewpoint, there is no organizational difference between the faculty and the Multidisciplinary School. Both have a Dean's Office, a staff of qualified teachers, a social support system and a Student Board. As far as education is concerned, the prerogatives and responsibilities of the Head of the School are identical to those of a Dean, the only difference being that research is carried out in laboratories managed by individual professors from various faculties rather than in the organizational framework of MSIB.

Since medical sciences are not represented in the AGH-University of Science and Technology, six medicine-oriented lectures (e.g. anatomy, physiology, medical deontology, history of medicine) are given by professors of the Collegium Medicum (Medical College) of the Jagiellonian University. The agreement between the universities gives students the opportunity to attend lectures and to participate in laboratory exercises in the Faculty of Medicine. This cooperation is reciprocally beneficial since it provides an alternative, i.e. technology-based viewpoint to our medical colleagues and medicine students. Unfortunately, current medical curricula in Poland do not include engineering aspects in medicine, however some lecturers from AGH-UST are among those who take part in postgraduate studies and technology-oriented teaching projects for medicine students or medical doctors.

2.3. General layout of curricula

The BME teaching programs in the Multidisciplinary School of Engineering in Biomedicine AGH University of Science and Technology follow all the Polish legal regulations, including the national standards for academic teaching set out by the Ministry of Science and Higher Education [6], and the guidelines of the Bologna Process (including the Educational Credits Transfer System and Accumulation System-ECTS). The current program presented in the block diagram in Fig. 1 consists of:

- A single 7-semester track leading to the First (Undergraduate) Degree (Bachelor's/Engineer's);
- Five domain-oriented 3 or 4-semester tracks leading to the Second (Graduate) Degree (Master's);
- A single 8-semester track leading to the Third Degree (Doctor's).

After a careful review of the needs from prospective employers' point of view, the availability of existing infrastructure and resources and a detailed study of reports from more experienced colleagues, we have decided to formulate and put into practice several rules and mechanisms that provide a broad basic education in all possible BME domains and fast adaptation of the program to the variability of an unstable, constantly developing local employment market [7].

A complete description of the content of our educational offer consisting of 189 lectures (tab 1):

- 64 for the Bachelor's (First) degree,
- 104 in five domains for the Master's (Second) degree, and
- 21 for the Doctor's (Third) degree).
- is available from the MSIB web service www.biomed.agh.edu.pl.

PhD (Third Degree) Studies also consists of a curriculum, but their essential part is an individual research program individually establihed depending on candidate and supervisor interest areas. Some selected themes for PhD theses may also be worth mentioning:

- 3D Reconstruction of Brain Glial Cells (2010),
- Automatic Facial Action Recognition in Face Images and the Analysis of Images in the Human-Machine Interaction Context (2009),
- 3D Segmentation of Medical Data from Computed Tomography and Endoscopic Video Records (2008).

Full texts of these theses are available on-line from the Biomedical Engineering PhD students' web service www.embio.agh.edu.pl.

Unlike many other departments, we accept candidates that graduated in a wide range of 'relative disciplines' as their First

Degree studies to apply to the recruitment process for the Second Degree at MSIB. The list of such disciplines contains today 33 faculties ranging from biotechnology to physiotherapy and from chemistry to computer science. Although we prefer the Engineer graduates (who had 7 semesters, 210 ECTS in the First Degree programme), we also accept a limited number (20%) of Bachelor graduates (who had 6 semesters, 180 ECTS in the First Degree programme). Such candidates apply in September and have to pass an individually tailored 'engineering course' in fall semester (see fig. 1) in order to learn selected skills which their colleague engineers acquire in the First Degree and to gain the remaining 30 ECTS.

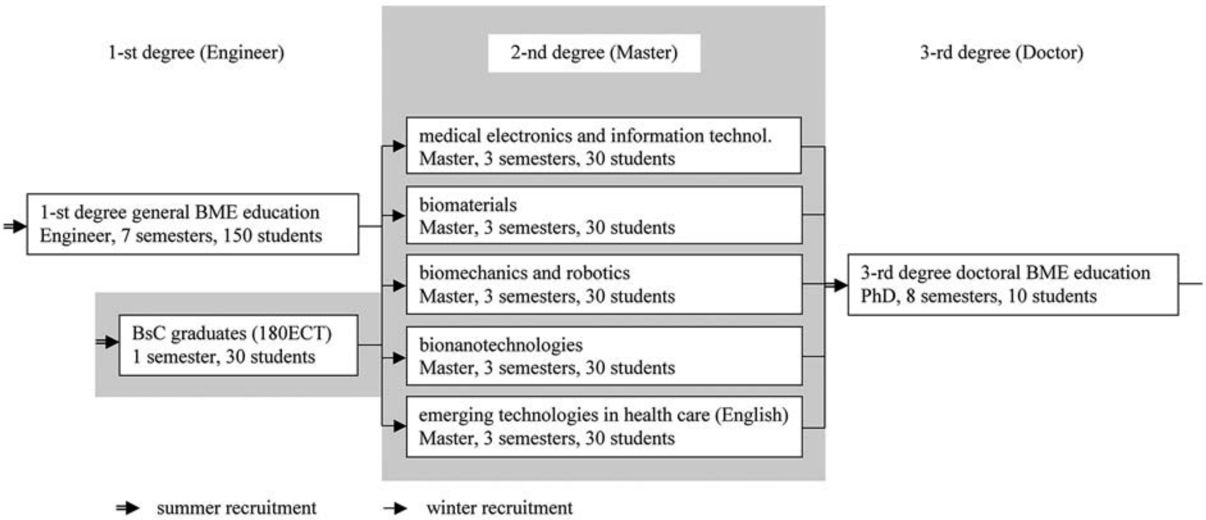

Fig. 1. Education track chart for biomedical engineering at MSIB AGH-UST

Tab. 1. Course list of the 1-st and 2-nd degrees of the *biomedical engineering* studies in MSIB and of the 3-rd degree studies in *biocybernetics and biomedical engineering* in AGH-UST

semester	1-st degree		semester	1-st degree (continued)
1.	• Information technologies • Mathematics • Physics • General chemistry • Biocybernetics • Biology and genetics • Propaedeutics of medical sciences		5.	• Foreign language • Medical Physics Biomechanics • Computer graphics • Fundamentals of graphical programming languages • Programming languages *-or-* Object programming • Automatics and Robotics
2.	• Mathematics • Physics • Statistics and probability theory • Principles of electrical engineering • Principles of electronics • Organic chemistry		6.	• Foreign language • Biomechanics – project • Implants and Artificial Organs • Electronic Medical Instrumentation • Medical Imaging Technology • History of medicine • Elective 1 – Cryptography and data ciphering systems – Chemometry – Ergonomics and occupational medicine • Elective 2 – Principles of management in biotechnical systems – Microcontroller programming in C/C++ – Globalization and modernization problems – Introduction to environmental philosophy – Glass- and glass-ceramic materials in medicine

semester	1-st degree		semester	1-st degree (continued)
3.	• Sport • Foreign language • Physics laboratory • Materials sciences • Principles of metrology • Mechanics and strength of materials • Fundamental anatomy • Principles of physiology • Computer programming		7.	• Introduction to diagnostics with ionizing radiation • Medical deontology • Introduction to philosophy • Legal and ethic issues in biomedical engineering • Diploma seminar • Engineer project and bachelor degree examination • Elective 3 – Biomineral science – Practical electronics – Programming of control and measurement systems
4.	• Sport • Foreign language • Computer Aided Design *-or-* Design with Finite Elements Method • Elements of Biochemistry • Biophysics • Biomaterials • Sensors and non-electrical measurements *-or-* Integrated measurement systems • Digital signal processing			

semester	2-nd degree		
	medical electronics and information technologies	biomaterials	biomechanics and robotics
1.	• Identification and modeling of biological structures and processes • Tissue and genetic engineering • Fundamentals of telemedicine • Neural networks • Electronics Systems for Clinical Applications • Information systems in health care • Picture archiving and communication systems • Elective 1 – Design of VLSI circuits – Multimedia systems in medicine – Advanced methods for programming of multithreaded applications	• Clinical trials • Ceramic Biomaterials • Polymer Biomaterials • Identification and modeling of biological structures and processes • Tissue and genetic engineering • Information systems in health care • Implantation technologies • Elective 1 – Electron microscopy in biomedical engineering – Neurochemistry and neuropharmacology	• Biomedical signal processing • Identification and modeling of biological structures and processes • Tissue and genetic engineering • Rehabilitation Technology • Biomechanical designs • Servomechanisms and advanced control systems • Control systems in medical devices • Visual surgery support techniques
2.	• Research of biomaterials and tissues • Dedicated medical diagnostics algorithms • Multimodal interfaces • Rehabilitation Technology • Medical imaging systems • Telesurgery and medical robots • Individual project • Elective 2 – Algorithms for medical image analysis and processing – Cognitive informatics	• Research of biomaterials and tissues • Composite biomaterials • Metallic biomaterials • Telesurgery and medical robots • Rehabilitation Technology • Fundamentals of applied crystalography • Individual project	• Research of biomaterials and tissues • Ergonomics • Intelligent materials and structures • Acoustical diagnosis • Information systems in health care • Telesurgery and medical robots • Image processing for surgery support • Individual project
3.	• Voice computer communication • Computer support for acoustic diagnostics • Fundamentals of embedded systems design • Diploma seminar • Master thesis and examination	• Fundamentals of regenerative medicine • Diploma seminar • Master thesis and examination • Elective 3 – Selected problems of neurobiology – Surface engineering	• Bionics • Pharmaceutical industry equipment • Diploma seminar • Master thesis and examination • Elective 3 – Computer aided of engineering – EPLAN – Pharmaceutical industry materials and designs – Nanotechnology

semester	2-nd degree	
	bionanotechnologies	emerging health care technologies
1.	• Symmetries and structures, solid body and molecules • Soft tissue physics • Polymers • Physics of thin film surfaces • Identification and modeling of biological structures and processes • Tissue and genetic engineering • Physical methods in biology and medicine • Information systems in health care • Elective 1 – Biotechnological challenges in biophysics – Instrumental analysis methods – Fundamentals of cell and tissue engineering – Structural backgrounds of cell biology	• Biomaterials and artificial organs • Electronics Systems for Clinical Applications • Information systems in health care • Physical methods in biology and medicine • Telemedicine and e-health • Tissue and genetic engineering • Assisted Living Technologies
2.	• Research of biomaterials and tissues • Magnetic nanomaterials • X-ray applications in biomedicine • Applications of magnetic resonance in biomedical research • Telesurgery and medical robots • Rehabilitation Technology • Introduction to radiobiology • Individual project	• Design of biomechatronical systems • Identification and modeling of biological structures and processes • Medical imaging systems • Research of biomaterials and tissues • Rehabilitation Technology • Telesurgery and medical robots • X-ray applications in biomedicine • Development of VLSI systems • Individual project
3.	• Optical method of matter investigation • Neuroelectronics • Diploma seminar • Master thesis and examination • Elective 3 – General and molecular genetics – Protein engineering – Leukocyte and cancer cells transportation – Fluorescent and confocal – microscopy – Molecular modeling of bioparticles – Photobiology and photomedicine	• Implantation Techniques • Introduction to Biometrics • Neurochemistry and neuropharmacology • Diploma seminar • Master thesis and examination
semester	3-rd degree	
1.	• Graph theory • Methods of systems optimization • Biocybernetics • Medical sensors and measurements	
2.	• Graph theory • Methods of systems optimization • Medical imaging in clinical practice • Biometry and medical statistics	
3.	• Information systems in telemedicine • Biomechanics and acoustics • Biomedical digital signal processing • Biomaterials and artificial organs	
4.	• Electronic medical instrumentation • Medical physics	
5.	• Medical image analysis • Modeling of biological systems	
6.	• Electives (2 of 6) – Dedicated algorithms for biosignal interpretation – Integrated systems SoC in medical diagnostics and therapy – Intelligent sensor arrays – Biophysics – Biological interfaces – Advanced equipment in medicine and rehabilitation	
7.	• Philosophy / Economy	
8.	• individual research	

3. International dimensions of BME studies at AGH-UST

The particular role of engineering in improvement of health care quality and accessibility manifests itself in Middle European countries. Here the technological advancement was constrained for a long time and organizational foundation of the health care was very rigid. Nowadays, there is a particular need in unifying the efforts towards technological improvement in hospitals, hospices, distant health care and medical awareness of the citizens. Leading regional research centers, such as AGH University of Science and Technology, where the development of many biomedical engineering branches is widely recognized, have the opportunity to bear the responsibility for international integration of these efforts. They also should support the advancement of prospective young researchers with the perspective of their future academic or industrial career.

Having in mind that BME learning and research environment is highly internationally oriented, the MSIB programme (particulatly master tracks) offers several opportunities for adding an international dimension to the knowledge and the practical experience of our students. The MSIB participates in this international society in several ways:

– establishing international contacts oriented for educational and scientific cooperation,
– proposing a complete master's track with its programme, lectures and courses in English,
– fostering students mobility and participation in international programs,
– making the foreign language education an important part of the study track.

3.1. International institutional relations

International contacts of MSIB grew out from scientific relationships shared by the members of its staff, in particular those of Programme Board. These relations are focused on one of the following aspect of cooperation:

– scientific (participating in a common research project),
– educational (being parts of students mobility programme or individually funded by foreign universities or industry),
– organizational (concerning the dissemination of experience about organizational aspects of MSIB and our BME educational programme).

Mentioning only contacts individually established with corresponding overseas partners, MSIB cooperates with Singapore University of Technology (students exchange), and Universitas Panamericana in Mexico City (organizational).

3.2. Education in English

Alhough starting a new faculty in Polish was a big challenge, it is worth a remark that MSIB is currently a forerunner of teaching BME in English. The track *Emerging health care technologies* offered in English in the Second Degree is dedicated to Polish students planning their career in international companies or in research centers worldwide as well as to foreigners planning their studies in Poland. This track offers most general BME knowledge and skills with particular stress on selected subjects accordingly to demand from industry and research. The skills include formulating of engineering problems in the area of biomedicine, solving such problems through modeling, designing, development and application of technologies with use of support from information technologies, information transmission and processing, leadership of development teams, innovation and creativity in ideas and implementation, decision making, etc. The offer of a complete Master's track with its programme, lectures and courses entirely in English enables easy access to our programme for foreign students. Currently the MSIB internationalize its information programme and is actively recruiting students from various European countries and from other continents.

3.3. Students' mobility

MSIB Program Board believes that staying abroad is a valuable component of the regular study. Student mobility also results in a more international composition of our master student population. Our students may carry out a part of their master's programme at a selected university abroad. In the framework of student mobility programme (e.g. Erasmus) our BME master's students may study up to one semester at another selected university. With some universities (e.g. Prague, Madrid, Lisbon, Paris, Grenoble, Saint Etienne, Twente, Magdeburgh, Trondheim, Lund and others) the MSIB has formal exchange contracts or has good personal contacts within the biomedical research groups. Student's exchange and participation in international projects influence the future career and in selected cases concludes with foreign or double diploma. The master's assignment abroad is still under the supervision of the professor of one of the MSIB-related research chairs of the AGH-UST and under the responsibly of the Master's Diploma Commission.

3.4. Foreign languages as a support for career

Being conscious of the international character of the discipline and striving for a competitive graduate as the outcome, the MSIB Board fosters foreign language education as a part of the regular study programme and justify additional costs we have to consider. The numerous advantages of this approach include:

– access to worldwide literature in English (including authorized access to papers of selected editors, e.g. IEEE),
– investment to a prospective career in Poland or abroad,
– support for international student exchange, etc.

Our goal is to make English the second language of every BME graduate, and to require B2-level communication skills in selected other foreign language (German, French, Russian, Spanish). Currently we offer additional courses in specialized English and German supported by BME-related teaching materials and topic-oriented language instructors. In case of French and Russian only general business language courses are offered. Foreign language courses are proposed as optional in the study track, however they are elected by a two-thirds majority of students.

4. Practical skills education

Biomedical engineering as any other technology-oriented discipline requires several practical skills to be acquired by students. In MSIB the practical aspects are particularly stressed in the programme by temporal restraint on the contribution of lectures far below 50% of the total obligatory contact hours. The programme also includes elective laboratory-based courses where students solve science-originating problems advised by leading researchers and in selected cases are invited to participate in the research. Several courses in the offer conclude with an examination for a nationally recognized certificate (safety in radiology, statistics in medicine, visual language programming, etc.) that may be of interest for the prospective employer.

Practical skills education is organized in one of four forms differing in length and expected outcome:

– laboratory exercise (1.5-3 hours), where precise tasks are expected to be completed with constraints of time in a prepared environment and reported following a given pattern,
– semester project (30 hours), concerning practical solutions of complex problems from literature studies to functional demonstration including report and symposium-like presentation,
– industrial internship (180 hours or 1 month), organized with cooperation with an industrial or health care partner to provide students with the opportunity to work in real conditions,
– diploma project (180 hours for Engineer and 300 hours for Master), where a complex problem is expected to be solved individually with documentation of engineering decisions evaluated by an independent reviewer and presentation against the Examination Jury.

4.1. Laboratory-based courses

Laboratory-based education of practical skills has several roles in the study programme:

– trains practical behavior in the laboratory or research office in various domains (biology, chemistry, physics, computer programming, electronic, metrology etc.)
– provides the student with a idea of future employment,
– gives a background for a result-based assessment of study progress.

In current study programme for Engineer Degree each student completes 31 courses with a minimum of 30 hours of laboratory exercises each (i.e over 900 hours in total). In Master Degree the number of laboratory-based courses varies from 12 to 19 depending on track.

4.2. Semester projects

Four independent semester projects are completed by students in Engineering Degree. Students split into project teams (2-3 persons) and apply for assignment of a complex task from the announced list (2nd week). In the application they specify their interest, skills, expected outcome and realization schedule. The project-based courses foster various skills necessary for an independent professional and a candidate looked after by most attractive employers:

– literature research and experiment planning,
– decision making and critical result-based review of own proposals,
– team working, interpersonal communication and time organization,

For each individual topic the project team is expected to provide an intermediate report (7th week), a final report (12th week) and a functional proof (13th week). Project-based courses end by a presentation seminar (14th – 15th weeks), where each team reports their outcome in a visual form and answers questions from the audience.

4.3. Industrial internship

A one month industrial internship is required by the programme in Engineer Degree and gives the students an opportunity to visit one (or two) of prospective workplace. Currently 62 institutions from the industry (20), health care (35) and research (7) are cooperating with MSIB. In some of them students have insight to details of manufacturing organization, in some others participate in research and development works. The internship is also a valuable opportunity for:

– independent assessment of the students' knowledge and skills provided by the supervisors from partner institutions,
– correlating the education programme with the demand from job market,
– promotion of the MSIB and the new discipline among the most related prospective employers,

Industrial internship is frequently asked to be completed abroad and students are likely to face this challenge. In summer 2010 six MSIB students participated in internship organized in neighbour countries: Belarus, Germany, Denmark, Netherlands and Swiss.

4.4. Diploma projects

Diploma project is completed individually under the supervision of a dedicated university professor, evaluated by an independent reviewer (sometimes from industry) and presented in front of Examination Jury. All project steps from the motivation to self-evaluation results have to be reported in print with clear distinction of student's contribution and justification of a reasoning path and decision steps. As the project is an essential part of awarding of the professional grade (BSc or MSc BME), particular attention is paid to revealing individual skills of each candidate as advantages for a future employer, and also in formal procedure the diploma examination resembles a candidate interview. Some diploma projects, particularly those related with international students' mobility are written in English. In MSIB we support such initiatives, as helpful for the future career of graduates.

5. Quality control mechanisms

Several aspects of novelty and uncertainty have been considered at the stage of foundation of the School:

– launching a new teaching discipline as independent study track, not being part or specialization within other discipline,
– organizing the multidisciplinary school, as independent unit of the university based on teaching staff of several supporting departments,
– introduction of two-tier structure of degree university studies (Bachelor's and Master's) with no experience and clear guidelines for curricula, syllabuses and examinations,
– changes of legal background for higher education in Poland aiming at synchronize local regulations to European standards.

Due to uncertain operating environment, and lack of predecessors all proposed solutions were considered tentative. Consequently, being responsible for the students' careers, we paid particular attention to implementation of quality control procedures, extended beyond the typical university regulations about teaching quality.

5.1. MSIB as a learning organization

As an optimum way to face with the necessity of instantaneous reaction to external conditions and remarks from inside of the educational process, selected principles of a learning organization [8] were applied:

– acquiring the knowledge and innovating fast enough to survive and thrive in a rapidly changing environment,
– creating a culture that encourages and supports the continuous learning of students and staff, critical thinking, and risk taking with new ideas,
– allowing mistakes, and appreciating bottom-originated contributions,
– learning also from experience and experiment, and
– disseminating the new knowledge throughout the organization for incorporation into day-to-day activities.

Additional advantage of this approach was fostering of BME-related virtues such as: technical excellence, adaptability, working in a multiprofessional environment and under the time pressure.

The School being for students an archetype of their future workplace is also expected to meet these criteria.

5.2. Quality benchmarks in a feedback

Teaching quality and its measure are fundamentals of the adaptive approach to BME education. Certain measures of quality were thus applied in the educational process and in the environment in order to take every opportunity to monitor students' knowledge, skills and attitudes.

Internal measures concern three aspects of teaching:

– students' quality – based primarily on the scores and qualitative assessment of the extramural outcomes,
– teaching staff quality – based on the students' questionnaire, employees' questionnaire and scientific outcome (carried out by mother faculties),
– educational process quality – based on students' questionnaire and scores analysis.

External quality benchmarks considers changeable operating environment (e.g. candidates quality and employers expectance). The benchmark list relies on relations of MSIB with industrial and health care partners and include:

– analysis of the industrial training reports,
– review of industrial opinions on students participating in competitions or internship,
– examination of BME teaching programmes from other universities, particularly based on practical observations gathered by students participating in exchange programs.

Quality benchmarks are systematically analyzed by teaching quality inspector, who presents the statistics and charts to the Programme Board. He also distributes selected remarks directly to lecturers (e.g. in case of two lectures are partly overlapping or examination questions are not sufficiently distinctive). The Board is deciding about modification of the study track, course form (lecture, laboratory, project etc.) or suggests an alternative lecturer in case of unsatisfactory result. Since there is no formal agreement between the School and the lecturer (teaching staff is employed by supporting faculties), the adaptation of personnel is not restraint by legal issues. In result of the quality-based selection, the BME students in MSIB have access to best teaching staff and best laboratory infrastructure available in the University without the institutional constraints.

6. Adaptation of teaching towards competitive graduates

Competitiveness of the graduates is a primary goal of education in MSIB. Paraphrasing the Ritz-Carlton's mission stating: "Ladies and gentlemen serving ladies and gentlemen.", we continue to write: "In the MSIB professionals work for professionals". Besides employment of best available professionals in the teaching process and recruitment of promising domain-oriented candidates, adaptation of the teaching is a most effective method to follow the expectations of job market. The adaptation is proposed from and executed by both educational partners:

– the Programme Board is responsible for the content of curricula, sylabuses and evaluation of teaching quality as well as for organization of occasional educational events,
– the students, which are involved in selection of elective and alternative courses as well as selection of their diploma projects.

6.1. Adaptation of curricula and sylabuses

In organizational formula of MSIB based on on-demand programme composition, the content of curricula (concerning the structure and schedule of the study track) and sylabuses (concerning the purpose and content of particular courses) may be easily adapted to particular needs. If a particular competence or skill is identified by the job market, the Programme Board simply asks best available teacher to prepare the course proposal and when he or she submits a suitable sylabus, the Board gives a final consent to implement the course into the study track.

The legal agreement with the selected teacher is limited for one semester (with a renewal option) and not constrained by his or her employing institution. The only limiting factors are:

– competences required by the Educational Standard (which restrains from eliminating of certain class of problems),
– proper management of expected students' workload (which can't exceed 30 class hours per week and the total workload of 900 hours per semester including self-study),
– availability (in financial and territorial aspects) of a suitable teacher.

6.2 Occasional educational events

Even in best universities the regular staff is rarely able to fulfill all educational demands, thus the curricula are complemented by occasional events like: summer schools, workshops, seminars and lectures given by visiting professors. In MSIB we implemented a systematic quest lecture covering vide range of problems given by topic-specific professionals from academia, health care or industry. These lectures are arranged with selected people from all the country (in the future also from abroad), based on their professional experience in various aspects of biomedical engineering. Despite industrial experts are not necessarily great teachers, the lectures are very advantageous to our students by approaching the realism of the profession difficult to be simulated in the university conditions and by presenting expertise not covered by regular university staff. The sample topics of guest-given lecturers are:

– Software-based management of a public hospital (given by a deputy director for the IT),
– How to apply for a BME project and justify its funds? (given by an expert-reviewer),
– Organizational issues and the role of engineers in Polish health care (given by an ex-deputy Ministry of Health).

Striving for development of international relations of our students we plan in the near future two editions of summer school. One of them is coordinated in the framework of European students' organization BEST, and the second is planned as a part of mutual students' exchange with the partner from Universitas Panamericana (Mexico City).

6.3. Elective and alternative courses

Elective courses are proposed in the 1-st Degree (Engineer) to students of 6-th and 7-th semester and in the 2-nd Degree (Master) to students of 1-st and 2-nd semester. Courses are dedicated to a particular semester (in the 2-nd Degree also to a particular study track) and proposed to students in a form of syllabus and usualy specify also the competences required for participation. By the announced deadlines before the semester beginning, students have to sign in for the selected course and since then it becomes obligatory for them to obtain at least a "pass" (i.e 3.0) score. A minimum number of 12 signed students is necessary for launching a course. Certain courses, for the organizational or security reasons, also specify the maximum number of participants.

Alternative courses are a kind of educational innovation at MSIB and help to face the challenge of working with outstanding students. Students of 4-th and 5-th semester may select between two levels of courses in computer programming, computer-aided design and measurement automation. While accordingly to the Educational Standard all these topics are obligatory, the basic level (e.g. "Programming languages") devotes ca. 70% of classroom time to cover the mandatory knowledge and the extended level (e.g. "Object programming") goes through the mandatory material in only 30% of classroom time. This acceleration, feasible with exceptionally skilled or particularly interested students, only recalls and systematizes their previously acquired knowledge and helps in development of their particular interest with avoiding of the waste of time. Although it is not a rule of alternative courses, the lecture of a basic and an extended course is given by the same person, which may adapt the difficulty level to the capability of particular students' group.

6.4. Projects as a tool for personalized development

As it was already mentioned in sections 4.2 through 4.4, projects and industrial internships play a crucial role in development of practical skills and of the idea the students have about future employment. Although standardized in the formal aspect, these elements are also helpful for:

– identification of particular abilities, strengths and weaknesses of each student,
– individualization of students' interest,
– university-independent research of the job market requirements and
– personalized planning of professional development.

Besides the employment-oriented individualization of the education, projects are considered by the authorities of MSIB as a valuable tool for building students' responsibility for their career, for fostering self-evaluation skills and orientation towards life-long learning. Consequently, tasks proposed as projects are reviewed every year with consideration of past results and new suggestions from the industry. Semester projects are evaluated and put forward by the lecturer and then supervised by assistant-professors. Diploma projects are individually proposed by prospective supervisors (having at least a PhD degree) and approved by the Programme Board. Among their aspects, the Board considers the educational value, the novelty and industrial applicability of the project and restrains the themes from being repeated before a three years period. As carrying out their project students are particularly encouraged to show their own initiatives, supervisors are committed to hear, consider and evaluate any students' input, especially suggestions concerning the actions planned in context of external conditions and personal abilities. In a series of individual meetings or through electronic exchange of information, students are individually guided and systematically assessed by their supervisors in course of the semester. Having received a final report, the supervisor evaluates not only the technical correctness of the completed project, but also the innovative approach and proper justification of each decision step which is of particular concern as essential engineering skill.

7. Results

In the case of MSIB, the adaptive approach resulted from the lack of predecessors in BME teaching and unknown employment conditions for future biomedical engineers. The adaptive education was implemented through organizational rules (Multidisciplinary School as a separate department of the University) and with adaptation of certain rules, particularly those of a learning organization. All means are oriented towards a successful career of each particular graduate. The adaptive approach reveals its additional advantages in general and individual aspects:

– in general aspect it allows for easy modification of the study programme under the control of the Programme Board composed of educational experts (with at least a DSc degree) from all BME-related domains,
– in individual aspect it supports the identification and reinforcement of personal skills and strengths of particular students, reinforces their self-assessment ability and reveals their care for the future professional career.

As first masters graduated this year, reliable statistics concerning the employment satisfaction are not available today. However, it is noteworthy that many students of the 2-nd degree already had their first job before the diploma examination. This particularity is observed also in other quality faculties in Poland: while in the middle of the study students striving for independent living get any occasional job, in the final period (last three semestrs) they become conscious of their skills and more demanding as employees. Some poor students satisfied with their first salary challenge the value of the diploma and sometimes leave the studies unfinished. Many good students temporarily sacrifice even their life standard to the investment towards their career by participating in additional courses or exchange programs or by applying for research projects or internationally recognized certificates.

For the purpose of independent evaluation of the engineering skills we organize the competition of engineering diploma projects. This competition is supervised and financially supported by the commercial partner who grants the prizes, but also provides a valuable feedback about students' skills. Last year, 26 projects (out of the total 84) participated in the competition and two of them assessed by the Jury as excellent were awarded the first prize ex aequo. During the dinner following the diploma gala, the winners had an opportunity to talk with the representatives of the health care commerce and industry.

As a preliminary outcome of the educational process, we consider the result of the written part of the engineering examination. The examination is based on the knowledge from 18 profession-specific courses represented in a total of 540 questions (30 questions per course). The question list is published in the Internet and thus available for students, however answers are systematically provided during the lectures and laboratory exercises. Technically writing, the examination consists of 50 single choice question randomly selected from the list by computer software (according to given rules helping to avoid unbalanced representation of certain courses). Each question is accompanied by up to four answers, and the answer correctness is coded in the software. Once the answer sheets are collected, the examinees' selections are copied to the software which issues the correctness percentage and the final grade. The people copying the answer sheets to the software don't know students' names nor which answer is correct. The examination is considered as objective as possible without using external experts. Additional advantage of using the software is issuing the results just few hours after the examination without involvment from respective lecturers.

First two years the engineering examination results were quite promising: the lowest percentage was 54%, which is still sufficient for a "pass" (i.e. 3.0) grade. The only concern is little number of highest scores: in two years only 7 students (out of total 164) achieved the correctness percentage over 91%, which is required for the highest "very good" (i.e. 5.0) grade. In our opinion this result is caused by certain specialization or preferences the students already have by the end of the 1-st Degree and consequent difficulty to maintain an equally high level of knowledge in all three domains of biomedical engineering.

Additional advantages of publishing the question list are:

– for candidates – the list is a clear specification of the study programme and the area of biomedical engineering, and
– for prospective employers – the list is a thematic context of the final score when our graduate presents his or her diploma during the job interview.

The diploma examination is intended to evaluate students' knowledge, however in MSIB we use it in the feedback improving the teaching quality. The results' statistics help to assess:

– the relevance of examination questions by investigating the average coherence of the general outcome and the question-specific results; a question is considered pertinent as much as the overall examination result may be predicted from the correctness of its answer,
– the difficulty of examination in context of the knowledge acquired from the lectures; the information on difference between the knowledge presented during the lectures and gathered by students is presented to the lecturer.

Both these assessment are considered as teaching quality benchmarks and thoroughly analyzed by teaching quality inspector.

Another factor that may be interpreted as a result of our teaching approach is the activity of students in national and international research areas. Surprisingly high percentage of students are involved in international mobility programs not only within the framework of UE-supported exchange (e.g. Erasmus-Socrates) but also in apprenticeships funded by companies (e.g. in 2011 four MSIB students were among 11 apprentices recruited by Siemens Healthcare out of 130 candidates) or positions in projects at overseas universities (e.g. in 2011 two MSIB students out of over 200 candidates were qualified for a project by Technical University of Singapore).

All presented remarks, although not replacing the statistical survey of employment, justify the hope that adaptation mechanisms applied in MSIB are adequate for achievement of high quality education and guarantee our graduates and their employers an optimal starting point for mutual satisfaction.

8. Concluding remarks

This paper shows essential elements of adaptive approach to BME teaching and the way they were implemented in Multidisciplinary School of engineering In Biomedicine. Short presentation was intended to justify the role of adaptive approach in maintaining high quality of the educational process, in involving students as partners responsible for their careers and in pursuit of the demand of job market. It is noteworthy that several ideas are advantageous in multiple aspects e.g. flexibility of the School and of particular lecturers is an archetype of adaptability of future engineers, international relations are crucial for the graduates, but also give references to our programme and independent evaluation of our efforts etc.

Adaptive approach may be recommended for other young disciplines not having established teaching rules and job market. The flexibility and ability of working in a multidisciplinary team in precisely specified time limits are features of high value for any employer. Usually, high quality teaching results in graduates easily finding their first job. However, the excellence we strive for manifests itself by demand for our graduates from prominent employers or even support for the most promising students.

9. Acknowledgment

This work is supported by the AGH University of Science and Technology as a research project No. 11.11.120.612

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