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Recent Developments in Biomedical Engineering Education and Research in Brazil

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Abstract— **The purpose of this paper is to present recent developments in Biomedical Engineering (BME) education & research in Brazil. The state-of-the-art in research in BME around the world is mentioned to highlight emerging technologies. A review of BME undergraduate, graduate & research programs in Brazil is presented. A roadmap of developing BME education in Brazil is outlined. Some critical implementation issues are mentioned.**

I. INTRODUCTION

Biomedical Engineering is advancing at an incredible pace making use of recent advances in Microelectronics, BioMEMS (MicroElectroMechanical System), Biomaterials, Biomedical Optics & Imaging, Computing, and Informatics, amongst other cutting edge areas. The BME profession involves application of engineering tools for solving problems in biology and medicine. BME students are trained primarily as engineers with basic foundations in engineering, medical sciences & biotechnologies and are expected to assert their multidisciplinary expertise in the design of medical devices and health-care systems for diagnostics and repair of human body by minimally invasive interventions.

A glance of few important magazines and journals reveals astounding array of research has been conducted in BME around the world in the last decade. BioMEMS Devices for Drug Delivery, Transdermal Drug Delivery by Localized Intervention, Ultrasound- Mediated Drug Delivery, & other works are described in [1]. Biomedical Engineering in China [2] presents amongst other works, C-Sight Visual Prostheses for the blind, Perspectives on High Technologies for Low-Cost Healthcare, Multimodality Molecular Imaging, and Noninvasive Imaging of Head-Brain Conductivity Profiles. Opportunities & Challenges in MR-Compatible Robotics, A Light Puncture Robot for CT & MRI Interventions, A General-Purpose Magnetic Resonance-Compatible Robotic System, Integrating an Image-Guided Robot with Intraoperative MRI, and many other papers are presented in [3]. Sensors for Brain-Computer Interfaces, Silicon LSI-Based Smart Stimulators for Retinal Prosthesis, Electrical Stimulation as Therapy for Neurological Disorders, and many more works are presented in Neurotherapeutics [4].

Noninvasive Measurement of Instantaneous Radial Artery Blood Pressure, Compliant Grasp in a Myoelectric Hand Prosthesis, Bipolar Coagulation-Capable Microforceps, A Decomposition Algorithm for Surface Electrode-Array Electromyogram, and many other works are reported in [5]. Innovations in Two-Photon Deep Tissue Microscopy are presented in [6]. Electrophysiological Models of Heart Cells and Cell Networks, the Forward and Inverse Problems of Electrocardiography, besides other works, are presented in [7]. The fundamentals of BioMEMS and medical micro devices are lucidly explained in [8]. Implantable Neurostimulation Devices are described in [9]. Applications of BioMEMS in Surgery are given in [10] – [12]. An Ingestible Capsule for Impedance and pH monitoring in the Esophagus is presented in [13].

The impact of the emerging medical technologies, randomly surveyed above, indicate that multidisciplinary BME education merits special attention to meet the demand of biomedical engineers for research, manufacturing and health industry. The development of cutting edge BME programs in developing countries pose difficulties where the research in MEMS, Micro technologies, Nanotechnology, Biomaterials, Medical Imaging and Optical Engineering has been less than adequate. The specialty areas within the field of BME are Bioinstrumentation, Biomaterials, Biomechanics & Medical Robotics, Medical Imaging and Informatics.

Bioinstrumentation is the application of microelectronics and measurement principles & techniques to develop devices used in diagnosis and treatment of disease. Biomedical signal processing, Sensor development and Medical device integration are required. Integrated Optics, Microelectronics, BioMEMS, Sensors, Lab-on-chip & Interface are typical subsystems of implantable devices.

Biomaterials deal with the general principles of designing, synthesizing, processing and characterizing biomaterials and their applications in the construction of biomedical devices like artificial blood vessels, cardiovascular stents, heart valves, breast implants, orthopedic implants, dental filings and intravenous catheters. Biomedical engineer is expected to selection an appropriate biomaterial keeping in mind interaction between proteins-cellular-implant interfaces. Biomechanics applies principles of mechanics and robotics for solving medical problems at human body, organ, tissue, cellular and molecular levels, which includes connective tissues such as ligament tendon, cartilage & bones; orthopedic implants; vascular remodeling; joint motor control and neuromuscular adaptation.

Medical Imaging deals with various medical imaging modalities such as conventional and digital radiography, positron and X-ray computed tomography, magnetic

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resonance imaging and ultrasound imaging to provide anatomical, functional and therapeutic information. Medical Informatics treats with resources, devices, and techniques to optimize the acquisition, storage, retrieval and use of enterprise wide healthcare management data, clinical data, medical images and digital pathology images via computer networks using Digital Imaging Communications in Medicine (DICOM) protocol and Picture Archiving & Communication Systems (PACS) software.

II. REVIEW OF BIOMEDICAL EDUCATION

An extensive search of the Brazilian public and private universities offering undergraduate, graduate and research programs in engineering , information science, biological sciences, medical sciences and allied health sciences was conducted on internet to determine BME educational capabilities in teaching and research. The data obtained were compared with the official sources, namely, CAPES, the Government agency for the perfection of higher education. (http://www.capes.gov.br/).

A Undergraduate Programs

The survey revealed that only four universities in Brazil have four years undergraduate degree programs in BME, [14] – [17]. About ten universities offer one introductory course in BME or in biomedical signal processing as an elective in Electrical Engineering; moreover, few other universities offer graduation projects in BME.

Biomedical Engineering Program at the Federal Univ. of Pernambuco, Recife [14] - The eight semesters program is divided into three cycles, namely, Basic, Professional and Electives. Reaching the professional cycle, students can opt for one of the four major areas, namely, Bioengineering; Rehabilitation Engineering; Medical Engineering, and Clinical Eng. Bioengineering deals with mathematical modeling and simulation of Neuro- and Cardiovascular systems. Rehabilitation engineering has objective of developing mechanical and electronic systems to improve the quality of life of physically deficient. Medical Engineering is directed to the design and execution of electronic instrumentation, sensors, and prostheses. Clinical Engineering deals with certification and testing of medical equipments and execution of projects. The BME/UFPE course has an international collaboration program with Technical Univ. of Compiegne, UTC, France.

Biomedical Engineering Program at Pontifical Catholic University of Sao Paulo [15] -The ten semester's program is run in collaboration with hospitals and companies. The program is structured in five major areas, namely, Medical Imaging; Clinical Engineering and Health Administration; Medical Electronics; Biomechanics & Rehabilitation Engineering, and Medical Informatics. In general, there are no formal lectures; instead, students are active learning elements under the guidance of professionals in the practical environment.

Faculty of Medicine, University of Sao Paulo at Ribeirao Preto [16] - The eight semester program offers bachelor degree in Medical Informatics since 2003 and the program has three major areas, namely, Bioinformatics; Medical Image Processing, and Health Administration & Epidemiology. Basic core courses include Molecular Biology, Anatomy, Biochemistry, Physiology, Genetics, Microbiology and Epidemiology along with the Physics, Chemistry, Mathematics and Computer Science. Professional level courses are Signal Processing, Machine Learning, Bioinformatics, Medical Image Processing, Computer Networks, and graduation project.

Biomedical Engineering, University of Paraiba Valley, Sao Jose dos Campos, Sao Paulo [17] - The eight semester program offers bachelor degree in BME. The first batch of BME students graduated in 2005. UNIVAP is the only private university in Brazil to offer complete programs of undergraduate, graduate and doctoral degrees in BME. The major areas of study are Medical Informatics, Clinical Systems, Artificial Tissue & Biomaterials and Biomedical Instrumentation.

B Graduate and Research Programs

About eleven public & private universities offer graduate and research programs in BME, mostly as a part of Electrical Engineering, leading to master and doctoral degrees [17] – [28]. The most common activities in the graduate programs are focused on the biomedical signal processing, medical image processing, and biomedical circuits. Moreover, there are few more universities where graduate studies and research is conducted in BME under departments like Mathematics, Physics, Computer Science, and Statistics.

Institute of Research and Development, University of Paraiba Valley, UNIVAP, Sao Paulo [17] has the following research group in BME: *Tissue Engineering, Biochemistry applied to BME, Vibrational Spectroscopy, Photoacoustics applied Biological Systems, Biophotonics, Biomaterials, and Biological Signal Processing.* The UNIVAP offers graduate program in BME in three areas of concentration: Biomedical Instrumentation, Lasers Applied to Biology & Medicine, and Biomaterials. The graduate program in Bioengineering has Diagnostics Systems, Therapeutics & Rehabilitation Systems, and Laser in Dentistry as areas of concentration. Few typical recent publications of UNIVAP are [29] - [32].

The Federal University of Rio de Janeiro [18] has one of the well established BME program in Brazil, offering master and doctoral degrees in the following six areas: 1. *Health Systems Engineering* - Analysis and modeling of epidemiological data and Computational Genomics. 2. *Clinical Engineering*- Hospital Safety, Metrology, Security tests & performance of hospital equipments. 3. *Processing of Signals and Medical Imaging* - Analysis of EEG & ECG by Neural Networks, Study of Hemodynamics by Ultrasound Doppler Signals, Gait & Postural Control of Biomechanical Systems, Processing of Radiologic and Ultrasound Images. 4. *Pulmonary Engineering* - Monitoring of cardio-respiratory

systems; Modeling of Physiological Systems. 5. *Biomedical Instrumentation* - Sensors; Bioimpedance Tomography, Monitoring of patients, and Muscular Rehabilitation. 6. *Ultrasound in Medicine* –Ultrasound transducers; Modeling of Ultrasound propagation in biological medium; Analysis of Blood Coagulation, and Ultrasound Biomicroscopy. Some recent IEEE BME Transaction publications are [33] - [40].

The Biomedical Laboratory, University of Sao Paulo [19] has contributed significantly to the famous Heart Institute of Brazil. The graduate program in BME was authorized in 1999 as a part of EE graduate program leading to master & doctoral degrees. The main research tracks are: *Biomechanics & Rehabilitation Engineering, Biomedical Instrumentation, Testing and Certification of Medical Equipments, Computational Neuroscience and Human Neurophysiology, Biological Signal Processing & Medical Image Processing.* Typical research publications are [41] - [43]. The State University of Campinas, UNICAMP, [20] is well known for BME research in Brazil [44] & [45].

The Bioengineering Department, University of Sao Paulo at Sao Carlos [21]; The Health Technology Program, Pontifical Catholic University of Parana, Curitiba [22]; The Federal Technical University of Parana, Curitiba [23]; The BME Laboratory, Federal University of Uberlandia [24]; The BME Department, University of Mogi das Cruzes, Sao Paulo [25]; The Instrumentation Laboratory, Federal University of Rio Grande do Sul [26]; The Institute of BME, Federal University of Santa Catarina [27]; and The Electrical Engineering Department, University of Brasilia [28] all have some research activities in BME leading to master and doctoral degrees.

The Biomedical Engineering research publications in Brazil can be confirmed by peeping into the Proceedings of Brazilian Biomedical Engineering Conference (CBEB 2008) [46] where about 300 papers were presented (some papers are in English) under the following tracks: *Biomechanics, Biomaterials, Biotechnology, Clinical Engineering, Medical Physics, Medical Informatics, Biomedical Instrumentation, Modeling & Simulation of Physiological Systems, Medical Imaging & Processing of Biological Signals, & Bioinformatics.* Moreover, twenty papers were presented at the IEEE EMBC2008 in Vancouver by Brazilian authors and fourteen papers are being presented at this EMBC2009.

C. Industrial BME Research Programs

Brazil has two strong public pharmaceutical institutions, namely, Institute of Butantan, managed by the Government of Sao Paulo State and the other is, Fiocruz Foundation, Rio de Janeiro, run by the Federal Government. Both Butantan and Fiocruz have research, manufacturing and academic sectors producing vaccines, drugs and diagnostic kits; and offering graduate and doctoral degree courses in allied health sciences and pharmaceutics.

There are twenty-nine multinational pharmaceutical companies in Brazil, mostly located in Sao Paulo and Rio de Janeiro, producing about eight billion dollar of medicines per year. The major laboratories are Pfizer, GlaxoSmithKleine, Novartis, Sanofi-Aventis, AstraZeneca, Johnson & Johnson, Roche, Merck, Abbott and Lilly, amongst other heavy weights. Most of these multinational companies have in-licensing and co-marketing agreements with the Brazilian partners. Except few companies like Abbott Brasil, other companies conduct research & development outside Brazil. Brazilian medical industry manufactures and exports dental materials & equipments, incubators, hospital equipments, and common medical supplies (needles, syringes, gauze, stents & condoms), some with foreign licenses; however, there are no major high-tech medical imaging, biomedical instrumentations, surgical equipments, clinical laboratory equipments, & implantable devices manufacturers in Brazil.

III. Roadmap of Developing BME Education

Even though a sizable BME educational capability exits in Brazil, however, in view of rapid advancements in BME, growing demand of BME graduates, and the need to strengthen some research & academic programs, essential for the growth of BME education , a roadmap of developing BME education is suggested:

A. Undergraduate Education

The academic institutions must offer new courses and programs to attract engineering students to BME: (a) Elective Courses - Medical Terminology, Physiology for Engineers, Cell & Molecular Biology for Engineers, Medical Imaging, Bioinstrumentation, MEMS, Biomechanics, and Biomaterials. (b) BME Minor in Electrical Engineering. (c) BME Minor in Mechanical Engineering. (d) BME Minor in Chemical Engineering. (e) BME Minor in Bioengineering. (f) BME Minor in Materials Science. (g) New Four years BME Programs with five specialization tracks – Medical Instrumentation, Medical Imaging, Health Care Systems and Medical Informatics, Biomechanics, and Biomaterials/Tissue Engineering. (h) New three years technology oriented programs in BME for service, sales, & manufacturing engineers with specialization tracks – Medical Devices, Hospital Equipments, & Clinical Laboratories.

B. Graduate Education

Create one year specialization programs in BME for the undergraduates in Medical Science, Engineering and Allied Health Science with the state-of-the-art technology contents. Project new 2 to 4 years graduate programs for M.S. / Ph.D. candidates with focus on cutting edge BME technologies.

C. Research Areas

It is suggested that research in the following areas be emphasized which are critical for the growth of BME in Brazil: (a) MEMS (b) LASERS (c) Medical Imaging Systems (d) Biomedical Optics (e) Microscopy (f) Tissue Engineering (g) Biomechanics (h) Bionanotechnology (i) Biomolecular Engineering & (j)Microfluidics/Lab-on-chip

IV. CONCLUSIONS

The proposed roadmap of developing BME education in Brazil is necessary to increase the supply of qualified human resources to enable the pharmaceutical & medical industries to stay competitive in the global market; however, there are critical implementation issues, among others, lack of qualified faculty in emerging areas, the inertia to migrate to new research areas in public & private universities, the lack of infrastructures in cutting edge research areas, and the short-comings of high school science education (K-12) & entrance tests for universities.

In last decade's private universities enterprise has grown enormously in Brazil, however, the fiscal and economic realities, and the lack of quality education pose problems. This survey reveals that Brazil has made huge progress in BME in spite of problems. To strengthen higher education & research in forefront areas, viable and unique solutions are needed. It is expected that BME education will boom in Brazil if right decisions are made.

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