Mechatronics in the education: the experience of the Technical University of Sofia in the context of the challenges of the modern development in education and industry

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Abstract

The analysis of the career development of students in engineering has shown that specialized education in Mechatronics is necessary to be designed. Thus Mechatronics has become one of the newest university specialties in Engineering. It combines knowledge in Mechanical Engineering, Electrical Engineering, Computer Science, and Control Systems. Such type of expertise is the present-day demand of the industry: it needs engineers who have interdisciplinary skills and ability to produce new ideas and products for the rapidly changing market. In this way educational programs in Mechatronics have been developed in many countries around the world including in the Technical University of Sofia. As a matter of fact, the education in Mechatronics varies in different universities in terms of concept, scale, and content. Some universities offer whole undergraduate or graduate programs, others have just individual disciplines. However, almost all educational institutions aim, in different forms, at integrating the basic engineering areas: Mechanical, Electrical, Computer, and Control Engineering albeit different universities place on emphasis on one or two of these four fields of knowledge and study: in the different universities even the programs or courses in Mechatronics are located in different departments – either in Mechanical, or in Electrical, or in Computer Engineering Departments. Another common feature of the proposed programs is the need for hands-on experience that allows the students to cultivate the expertise to design Mechatronic systems on their own and thus to be able to develop promising engineering careers. There are differences amongst the different educational institutions in the number and kind of the disciplines taught, in the instruction approach, and in the structure of laboratory exercises, in the projects tasks and requirements.

This paper reviews attitudes towards and program features of Mechatronics education in several countries. Further, in the context of this survey of approaches and attitudes towards the education in Mechatronics, the paper discusses the concepts behind the curriculum of the program of Mechatronics in the Faculty Mechanical Engineering at Technical University Sofia in Bulgaria and analyzes the disciplines incorporated in this program.

1. Education in mechatronics around the world

The broad area of Mechatronics education provokes different approaches in preparing students for the dynamic market of highly integrated products. Some universities organize such education programs within a given department (Mechanical, Electrical, or Control) or with the cooperated efforts of several departments. Some curricula include subjects not from all four basic engineering areas or are concentrated around one spinal discipline (e. g. control engineering). The differences are caused by the views of the educating bodies and by the needs of the local industries.

If we follow the history of mechatronic studies, we may point out several approaches. In [1] Craig puts the stress on the "balance between modelling/analysis skills and hardware implementation skills". He also asserts the need for mechanical engineers to be proficient in control design in order to produce novel concepts in their design activities. They should include modelling, simulation, and analysis together with their former hardware experience in generating new prototypes together with engineers from other areas. There are two senior elective courses in the Rensselaer Polytechnic Institute, "Mechatronics" and "Mechatronic System Design", each lasting for one semester. Craig describes the programs as helpful for the engineers in learning how to apply the classical control designs as an incorporated part of their own design. Students are taught with an emphasis on understanding the physical and mathematical fundamentals. The main issues are Modelling and Analysis of Dynamic Systems, Feedback Control of Dynamic Systems, analogue and digital electronics and control implementation and simulation with latest software. The first course includes lab exercises with five Mechatronic systems, while the second one includes projects for four-person teams that fully develop Mechatronic systems and present them in written and oral form. Craig also emphasizes on the need of experience of the instructing stuff in order to teach modelling.

Wikander et al. [2] claim that a new Mechatronic approach is needed where a shift from mechanical hardware to computer software is established in implementation of functionality. The older subsystem-based approach of designing the separate homogeneous subsystems and interfacing them afterwards does not provide the full integration of the design process of a given mechatronic system. They propose as an educational approach the system in the Swedish Royal Institute of Technology with a five-year curriculum where interdisciplinary courses are integrated in an existing program of mechanical engineering. The courses usually deal mostly with the design process and the acquired knowledge of the various engineering disciplines by the students is achieved by problem-based learning, with team organization. Examples of courses in the Institute above following the given principles are: "Microcomputers in Embedded Systems", "Advanced Course in Mechatronic System Design", "Real-Time Control and Programming".

Alciatore [3] asserts restructuring the core mechanical engineering undergraduate curriculum toward mechatronics program, as well.

Siegwart [4] provides a discussion on mechatronics education in the Swiss Federal Institute of Technology of Lausanne (EPFL) and ETHZ, Zurich, and particularly the "Smart Product Design" course in the latter one. Students there "bond" their basic interdisciplinary knowledge of elements of mechatronic systems, electric circuits, sensors, actuators, controllers, control and artificial intelligence, etc. with the help of design, system integration, teamwork, project management, communication and controlling activities. They gain all the skills through projects where theory meets practical illustration. The projects consist of building mobile robots, where every student team receives a kit ("smart ROB design kit") and an assignment for the tasks the robot should be able to fulfill. Before starting, the participants in the "Smart Product Design" course have both lecture and laboratory work. Various subjects are covered that are not all familiar to the students and the latter communicate with engineers from different areas in order to achieve the integration required in the mechatronic system design. In the end of each course, all robots from the projects participate in a contest. This element adds more motivation to the studies.

The practical education is an emphasis also in the Ritsumeikan's Department of Robotics [5]. The exercises in the courses of advanced robotics there are held from the second until the last year in the university. As for the previous case system, integration is a basic purpose for the students to achieve. Despite the great difficulties they meet, they receive background knowledge and experience in order to proceed with their careers and research in robotics.

In [6] Tomizuka states: "Issues surrounding integration as well as working in team cannot be taught in lecture courses. Students must experience them, and in this regard laboratory courses are essential in mechatronics education". In addition, he emphasizes on the need for drawing the attention of students toward mechatronics at an early stage (high school and college) and that IT tools have to be broadly incorporated into engineering education. Tomizuka describes a 15-week course in mechatronics design that covers various disciplines and ends with the presentation of projects developed by 3-4-person teams.

Brown et al. [7] express their preference toward the approach of project based practical engineering and to support it with theoretical learning. They place the basic questions concerning mechatronics education about the owner of this type of courses, the contents, and the way to "teach such a different philosophy with such a wide range of diverse subjects". The solution attained at Hull University is the control engineering part to be the spinal subject and other subjects come from other departments. The four-year mechatronics program contains mostly project work and supporting lectures. Active learning and quick adaptation are aimed by solving a large-scale design problem, which is put in place of traditional predetermined lab exercises. According to the representatives of the university, self-reliance, motivation, creativity and understanding are built in students by following that approach.

Mechatronic education at the University of South Carolina is being developed together with programs of Smart Structures and Adaptive Materials in the Mechanical Engineering in cooperation with the departments of Electrical Engineering and Computer Science. Giurgiutiu et al. [8] discuss the work at the university toward finding methods to teach multidisciplinary courses and organizing multidisciplinary project working teams. They state: "Today's and tomorrow's products are intertwined blend of mechanisms, sensors, actuators, electronics, and information technology. The ideal graduate should be able to hit the ground running in all these areas concurrently in order to achieve maximum performance with minimum training time. Of course the "ideal graduate" is not a physical reality but a graduate with a broad Mechatronics education will come pretty close to it". A track system, similar to that in the University of Washington, is proposed, where the courses are to be covered by the Electrical and Mechanical Engineering and the one of the tracks is Mechatronics.

The course sequence in Mechatronics in the University of Arkansas at Little Rock described by Wright [9] is a supplementary one for the system-engineering program there. The pursued task is to teach mechanical design to the students of that program. The multidisciplinary character of this type of undergraduate education is formed by the following sequence: Introduction to Engineering, C Programming, Elements of Mechanical Design, Circuits and Systems, Digital Systems, Control Theory, Instrumentation and Measurements, and Mechatronics (in the senior level) together with CAD/CAM laboratories and lectures. The design skills are the target of a free-form design project where students have to develop, analyze, simulate and produce a prototype, concerning also cost and budgets. A special competition (US FIRST design competition) in building a tele-operated mobile robot in 42 days is an additional task for the students of the university to enhance their training in cooperation with pre-college students.

An open-ended project is developed for the undergraduate Mechatronics course of Stanford University. Carryer [10] describes it: "The intent is to teach mechanical Engineering students enough about electronics and software so that they will be able to be effective interdisciplinary team members and leaders. The philosophy is that the best way to learn the capabilities of the technology is to actually learn to apply them oneself". One-quarter course contains this project, while a four-quarter sequence in Mechatronics is provided at the same university at the same graduate level.

The graduate Mechatronics course in the Woodruff School of Mechanical Engineering at Georgia Institute of Technology [11] is concentrated on the microprocessors and microcontrollers in mechanical systems. The course contains considerable part of hands-on design and work (usually in teams of couples of students) and ends with a final project also organized in teams. Computer programming and electrical engineering disciplines are mostly covered. Laboratories have large workspace and are devoted to particular skills. The projects are given additional time so that the students can develop proper aesthetic and packing features of their mechatronic products.

A new systematic approach to understanding of education in Mechatronics is suggested in [12]. The new paradigm assumes that the education environment is inevitably characterized by synergistic integration, including globalization, localization, and individualization at different levels and in different aspects of the industrials system. Synergism and integration in design set a mechatronic system apart from a traditional, multidisciplinary system.

2. Master degree program in Mechatronics at the Technical University of Sofia

Many new Mechatronics courses have been developed all over the world during the last years [15,16,17,18]. Those courses have been developed either mechanical engineering departments or electrical engineering departments and very rarely in computer science ones. In practice, now the majority of them are offered in mechanical engineering departments [14] as is the case at the Technical University of Sofia. The education in Mechatronics has gradually emerged in Bulgaria during the last ten years and had been located in the Mechanical Engineering Faculty of the Technical University of Sofia [13]. It has been developed with the help of the DAAD Project "Mechatronics", Pact of Stability in which universities from the following countries participated: Germany, Hungary, Slovenia, Serbia, Macedonia, and Bulgaria (2000-2006).

At the TU-Sofia, we consider that what is of utmost importance is to achieve balance of the disciplines in the following fields of study and research: mechanical engineering, electrical and electronic engineering, control systems, and information systems. Also, we pursue to reach balance in the development of the following skills: theoretical knowledge (ability of modeling and analyzing) and experimental validation of models and design. For this purpose, all the disciplines in our master program in Mechatronics are grouped in modules with recommended coefficient of weight of those modules in percentage as follows:

1. Basic Science Module – more than 20%
2. Mechanical and Measurement Engineering module – more than 20%
3. Electrical and Electronically Engineering module – approx. 20%
4. Information Technology and Computer Science module – approx. 20%
5. Control Engineering module – approx. 10%
6. Humanities and Management module – approx. 5%

Students who enroll in Master program in Mechatronics are usually those who graduate as bachelors in Mechatronics, Mechanical Engineering or Electrical Engineering. Students with bachelor degrees in Mechanical Engineering who enroll in Master Program in Mechatronics are supposed to take a special extra course in "Fundamental in Electrical Engineering" (about 10 credits). Students with bachelor degrees in Electrical Engineering have to take an extra special course in "Fundamental in Mechanical Engineering" (about 10 credits).

The Master program in Mechatronics at the Mechanical Engineering Faculty aims at providing students with interdisciplinary knowledge and skills, integrated design approach, manufacturing and maintenance of products and processes. More precisely the topics that are to be covered in this program include: system design (selection of sensors, actuators, electronic components and computer simulation), microprocessor technology (system architecture, digital systems, memory storage devices, input/output devices), interfacing techniques, digital communications, software development, and control systems.

The **Selected Topics in Mathematics** are aimed at the increased practical knowledge of set theory, images, mathematic statistics, experiment planning, graph theory, probability theory, etc.

Selected Topics on Mechanics is an extension of the "Mechanics I and II" from the undergraduate program. It contains topics from the analytical mechanics and vibrations theory, and discrete multimass systems connected with the design and analysis of transport and hoisting machines, building machines, robots and manipulators.

The **Basics of Mechatronics** course provides knowledge of the structure, functions, environment of the mechatronic systems, as well as their basic elements. An emphasis is placed on the methods for mechatronic systems design; concept preparation, planning, object design, etc. The theoretical bases for mechatronic systems modeling and different models of mechanical building elements, electric actuators and machines are reviewed.

Various technologies and technological processes are taught in the **Micromechanics** subject, which are used for the production of micromechanical structures. Technological equipment for their production and operations control means is reviewed. The design methods of micromechanical elements, the production technology development, and assembly methods are covered. The laboratory exercises provide an analysis of the available equipment design, optimal technological parameters settings of the equipment, and concrete production operations of the students for preparing micromechanical modules.

The theoretical issues of the optical and optoelectronic devices and specific solutions of some groups of such devices are covered in the subject **Optic and Optoelectronic Devices**. There are included the principle schemes of the basic types of optical, optoelectronic and laser systems that are used in industry and for research, the typical units of these systems, optical and fiber-optical sensors. The laboratory exercises give the students some skills in the operation in the use of optical and optoelectronic equipment, the ability to choose the right one for a given task in their future engineering careers, and to communicate with specialists in the given area.

The lecture material in **Reliability of Machine Products** deals with the problems and methods for planning, determining, normalizing, providing the reliability of products during their design, manufacturing and exploitation. Some issues here are basic reliability models, Markov models and processes application, processes that impede reliability and the influence of design and technology on them, methods for diagnostics of machines, systems and processes, etc. The laboratory exercises include some the investigation of the processes that impede reliability, calculation methods and the creation of algorithmic methods for reliability modeling and analysis, as well as diagnostic experiments with specialized equipment and software.

The discipline of **Engineering Analysis and Simulation Modeling** covers the types of models, their application in engineering analysis, practical problems in machine and appliance building through static and dynamic models, stochastic processes, experiment data analysis, regression analysis, dispersion analysis, correlation analysis, experiment planning, simulation methods. Students are provided with skills in working with the basic software products in this area.

The purpose of the subject **Mechatronic Systems with Multi-joint Structures** is to introduce the students with the kinematics and dynamics of these Mechatronic systems, the method of impedance control, Mechatronic systems with closed multi-joint structures, and new types of Mechatronic systems. The experimental work is carried out with software programs for dynamic modeling and simulation and analysis of the results is made.

Intelligent Control and Technical Vision subject covers topics on the methods of modeling, identification, and simulation of incompletely defined structures, digital, adaptive and intelligent control, synthesis and optimization in control problems, increase of system autonomy through artificial intelligence and acquisition of sensor information, technical vision systems, object recognition, video information processing, communication and integration of these systems with the other components of the Mechatronic systems. Both laboratory models and industrial devices and software are used.

Sensor and Actuating Systems contains issues on acquisition, conversion and processing of information from sensors, integrated sensor schemes, integration of sensor, actuator and control systems. The laboratory exercises improve the understanding of the theoretical material.

The subject of **Technical Legal Issues and Law** presents basic knowledge about the application of normative acts in two directions: the normative order of the firms and economic units according to the issues of the civil and trades law; the obligatory and the voluntary regulations for manufacturing and selling safe ant qualitative machine products. The purpose of the Industrial Management discipline is to provide knowledge about the basic problems in managing the industrial organizations, management thinking and functions. The lectures review also the contemporary concepts and systems for the effective business management. The practical exercises are in the form of cases, tests and problems.

Intelligent Manufacturing Systems provides the students with knowledge about the application of artificial intelligence and the integration of manufacturing and computer systems. Main issues are: historical development and today's problems of artificial intelligence, data bases, and knowledge bases connected with machine building, expert systems, IMS in robotics, etc. An emphasis is placed on the application of IMS as a base for the "Factory of the Future".

Advanced Motion control is a course related to automation. Students are taught how to control the position or velocity of machines by the use some type of power devices such as linear actuators, electric motors, hydraulic pumps and others. Motion control is an important part of robotics, CNC machine tools, automated production and assembly lines and many others.
At the TU-Sofia we pay a special attention on practice and research work considering that this is a very important part of the education on Mechatronics. All our master students are asked to design and elaborate a mechatronic device. On the pictures below some examples of students work is presented [19,20].

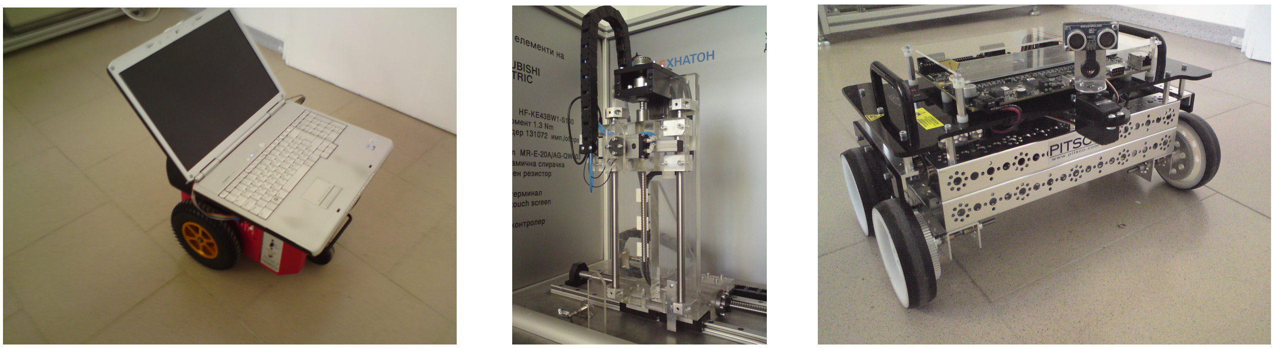

Figure 1. Examples of Mechatronic devices developed in the Technical University of Sofia.

3. Conclusions

Judging from the experience of universities all over the world and from our own experience in the education in Mechatronics, we believe that the most important components of such education is to achieve project-oriented programs, work in team and communication with engineers from different areas, systems integration in the design process, competitive approach in pursuing project tasks.

The education in Mechatronics at the Technical University Sofia has already reached some of the goals mentioned here but, in our view, it still lacks the hands-on approach because of the economic difficulties that all the countries meet today.

It is extremely useful for us to become familiar with international programs and experience and to implant them in our programs for Mechatronics engineers. It is essential for our university to have cooperation in the education of such specialists. Furthermore, we do our best to arrange for our graduate and undergraduate students to work on projects connected with the specialization of companies in Bulgaria, some of them international in character. We believe that these initiatives, to secure exchange of information, knowledge, and practice with other universities and with companies, are the necessary steps we can make to produce competitive Mechatronic engineers.

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