Inteligent Manufacturing Systems And Mechatronics – An Educational Approach

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Ab*stract:* The new demands of the industry and educational trends have caused the appearance of the new course of Mechatronics in the Technical University – Sofia in Bulgaria. The discipline of Inegligent Manufacturing Systems (IMS) has been integrated in it, as well as in other specialties. This approach is one of the various ones that have been developed throughout the world.

1. INTRODUCTION

The new demand on engineers for interdisciplinary skills and knowledge and the ability to produce fresh ideas and products for the fast changing market caused the development of educational programs in IMS and Mechatronics in many countries around the world. These programs vary to some extent in their concepts and contents. Different universities offer whole undergraduate or graduate courses or just separate disciplines in these specialties. However almost all educating institutions stress on the integration of the basic engineering areas: Mechanical, Electrical, Computer and Control Engineering. Another common feature of the proposed programs is the need for hands-on experience that allows the students gain the ability to design intelligent manufacturing systems and mechatronic systems on their own and the perspective to start promising engineering careers. There are differences in the number and kind of taught disciplines, the instruction approach, and the structure of laboratory exercises, the projects tasks and requirements. This paper reviews attitudes toward and program features of IMS and Mechatronics education in some countries. It also presents the concepts and the curriculum of the course of Mechatronics in the Mechanical Engineering Department in Technical University – Sofia in Bulgaria and the IMS discipline incorporated in this course.

2. IMS AND MECHATRONICS EDUCATION AROUND THE WORLD

The broad areas of IMS and Mechatronics education provide for the different approaches of preparing students for the dynamic market of highly integrated products. Some universities organize such education programs within a given department (Mechanical, Electrical, and Control Engineering Department) or with the cooperated efforts of several departments. Some programs 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.

Craig (2001) puts the stress on the “balance between modeling/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 modeling, simulation, analysis, and mathematics 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 Modeling and Analysis of Dynamic Systems, Feedback Control of Dynamic Systems, analogue and digital electronics and control implementation and simulation with latest software products. 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 modeling.

Wikander et al. (2001) claim that a new mechatronic approach is needed where a shift from mechanical hardware to computer software to be established in implementation of functionality. According to them 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 (2001) asserts restructuring the core mechanical engineering undergraduate curriculum toward mechatronics program, as well.

Siegwart (2001) 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 (“smartROB 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 (Nagai, 2001). 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.

Tomizuka (2002) states:

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"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 and Brown (2002) 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 laboratory exercises. According to the representatives of the university above, 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 Department in cooperation with the departments of Electrical Engineering and Computer Science and Engineering. Giurgiutiu et al. (2002) discuss the work at that 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/adaptation 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 Departments and the one of the tracks is Mechatronics.

The course sequence in Mechatronics in the University of Arkansas at Little Rock described by Wright (2002) 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 teleoperated 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.

The graduate Mechatronics course in the Woodruff School of Mechanical Engineering at Georgia Institute of Technology (Ume et al., 2002) 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.

An open-ended project is developed for the undergraduate mechatronics course of Stanford University. Carryer (2002) describes it and states:

"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.

3. IMS AND MECHATRONICS IN TECHNICAL UNIVERSITY – SOFIA, BULGARIA

The education in IMS and Mechatronics emerged gradually in Bulgaria during the last six years in the Mechanical Engineering Department and the English Language Department of Engineering (ELDE) of Technical University – Sofia. This academic year the former department offers a graduate program in Mechatronics. IMS is taught within the course in CIM. The graduate program of ELDE in Industrial Engineering provides a one-semester course in both disciplines.

The basics of IMS and Mechatronics have been seeded during the last decade with the fast changing demands of engineering specialists in automation and computer integrated manufacturing. Still in 1991 an educational concept in this area exists although the interdisciplinary idea is not yet well estimated. An emphasis in this concept is placed on the students' preparation for increased computer technology application, broad technical knowledge, and design skills concerning functionality and improvement tendencies, CAD, manufacturing processes development and control, basic economic knowledge. The educational process is proposed to be more problem-oriented and less specialized. A training complex is integrated in the training programs that contains modules for producing and assembling small wooden or plastic parts and is used to simulate a real computer integrated manufacturing system. The discipline of adaptive control has been included in the education program of the Mechanical Engineering Department with the help of the Chair of Automation of Discrete Manufacturing, and the disciplines of Technical Image Processing and Artificial Intelligence in Manufacturing have been developed with the help of TEMPUS projects. There has been useful collaboration within the TEMPUS program with CCTA – Wales and De Monfort University, Leicester, UK that have been supplying the department with modern computers, software didactic materials and scientific literature.

In February 2000, a symposium has been held in Sofia on the theme of "Mechatronics Education". The participants have been from: the Departments of Mechanical Engineering and Electrical Engineering, Technical University - Sofia, the Departments of Mechanical Engineering of Technical University - Illmenau, Germany, Technical University - Nish, Yugoslavia, and Technical University - Skopie, Macedonia. The reports have been connected with the research and educational experience of the different universities. A mutual intention has appeared for the creation of a net of universities to cooperate in this area. The purpose of the future cooperation is to provide for the basis of Mechatronics education aimed at application in the machine building, automatic and precise devices, as well as in micro-technologies and bio-technologies. Another important purpose is to create a common taxonomy for teaching Mechatronics.

Some professors in the Chair of Automation of Discrete Manufacturing participate in a project financed by DAAD (a German organization for academic exchange), in the part of "Mechatronics" with its leader - Professor Helmut Vurmus. An enlargement of this cooperation is planned connected with the Institute of Fine Mechanics and Optics in Technical University - Budapest, Hungary.

The Chair of Automation of Discrete Manufacturing has training and research laboratories in CAD, Assembly Automation, Control Systems and CIM class where most of the practical exercises are held. The training in IMS and Mechatronics is combined with intensive use of information technologies, multimedia, teamwork, and reports preparation, making successful presentations.

Strategies for IMS and Mechatronics education have been blended with those for CIM course. Some special modules introduced there are Hardware and Software CIM Platforms, Integrated Manufacturing, Non-automated Factory of the Future, Multimedia Technologies in Design, Concurrent Engineering, and Low Cost CIM for Small and Medium Enterprises. The existing teaching experience is proposed to be transferred to IMS courses concerning the following problems: the use of systematic approach for successful and effective automation; application of optimization techniques; analysis of artificial intelligence application in manufacturing systems in the aspects of adaptive control in production and assembling, artificial vision, intelligent CAD/CAM/CAE systems.

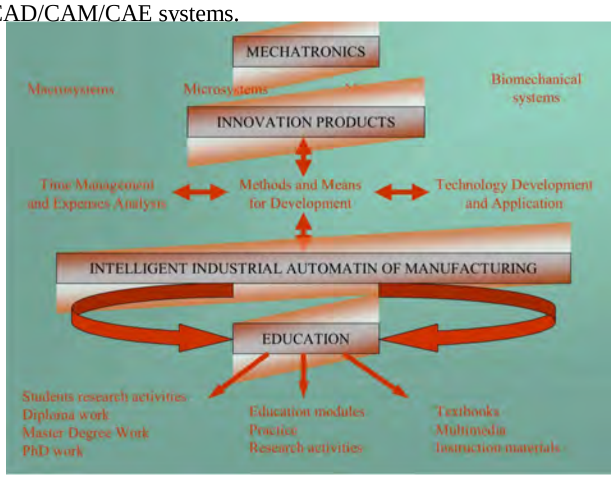

Figure 1. The Concept of the Future Activities in the Mechatronics Education

The Mechatronics program at the Mechanical Engineering Department is aimed 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. IMS education is incorporated as a subject in the course of Mechatronics in the department above and in the graduate course of ELDE.

Training in IMS and Mechatronics are supported still in the undergraduate level in both departments mentioned above. The first two years provide knowledge of fundamental principles of engineering sciences with the disciplines of Mathematics, Physics, Theory of Machines and Mechanisms, Electrical and Electronics Engineering, Computing, etc. the next two years provide special topics and some disciplines are elective. The Mechanical Engineering Department offers for example Low Cost Automation, Design of Automatic Machines, Computer Science, Quality Control, Technology of Discrete Production, Computer Integrated Manufacturing, Control Systems, etc. The ELDE program ends with Bachelor Degree in Manufacturing Engineering and interdisciplinary subjects in the second two years include: Control Engineering, Measurement and Instrumentation, Elements of Industrial Automation, Computing, Industrial Electronics, Manufacturing Design with projects and course works, CIM, CAD, Advanced Control Theory, etc.

IMS and Mechatronics in the graduate course of ELDE are taught as two separate modules of one and same subject in the Bulgarian Academy of Sciences by professors from the Institute of Mechanics and Biomechanics and the Central Laboratory of Mechatronics and Instrumentation.

The IMS discipline is incorporated in the Mechatronics course and is taught during the third semester. Here follow details about the Mechatronics course in the university (Fig. 2).

Figure 2. The Mechatronics Course Program in the Mechanical Engineering Department of Engineering

The purpose of the CAD/CAM Systems subject is to get the students familiar with the development and application of these systems and provide them with the ability to choose the suitable system for a given task. The laboratory exercises are devoted to work with AutoCAD, Mechanical Desktop and SolidWorks, as well as to the use of the corresponding CAM systems and the generation of the program code for a given CNC machine. 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".

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CONCLUSION

The most important features of the education in Mechatronics concerning the world experience according to the information we have gathered are: project-oriented programs, team working and communication with engineers from different areas, systems integration in the design process, competitive approach in pursuing project tasks.

The education in IMS and Mechatronics in Technical University – Sofia has started its development, but it still lacks the hands-on approach because of the economic difficulties that all the country meets today.

It is extremely useful for us to become familiar with the foreign programs and experience and to implant them in our programs for Mechatronics and IMS engineers. It is essential for our university to have cooperation in the education of such specialists. Furthermore, our graduate and undergraduate students can work on projects connected with their own studies in Bulgarian and foreign firms in our country. These initiatives are the steps we can make to produce competitive Mechatronic engineers.

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