Course 5: Mechatronics - Foundations and Applications

Introduction to Mechatronics and Mechatronics in Real Life

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Abstract

Mechatronics is a natural choice for explaining a process that seeks, from the outset, to generate definitive engineering system solutions, which are inextricably bound by those integrating technologies associated with the inveterate mechanical, electronic and computer based disciplines. Mechatronics opens up enormous technological possibilities, as already evidenced by the appearance of sophisticated products like ever-smaller camcorders and compact disc players. These would never have been plausible by adopting a traditional single disciplinary or combinational approach. By definition, then, Mechatronics is not a subject, science or technology per se - it is instead to be regarded as a philosophy - a fundamental way of looking at and doing things, and by its very nature requires a unified approach to its delivery.

The traditional western approach has relied on single discipline identities and evolutionary solutions based on bolt-on technology. On the other hand, Mechatronics solutions require the use of integrated teams of personnel working towards a common goal. Thus the Mechatronics engineer identifies with systems thinking, and a philosophy that lies behind it all. A Mechatronics 'product' derived through systematic, rather than piecemeal processing. It, therefore, seeks to optimize an 'engineered' solution rather than compromise it. Mechatronics philosophy adequately describes the process by which it is achieved. This insight quite naturally lends itself to the concept of 'total quality', something that western industrialized nations have only in the last decade or so come to aspire to. But for Mechatronics, quality is already implied by the way in which system based solutions are to be sought, and the methodologies used for achieving it. It is hoped that industry and commerce will similarly come to respect and aspire to Mechatronics for what it stands for - total synergy.

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1 Introduction

The word mechatronics was first introduced by the senior engineer of a Japanese company [1]; Yaskawa, in 1969, as a combination of "mecha" of mechanisms and "tronics" of electronics, and the company was granted trademark rights on the word in 1971. The word soon received broad acceptance in industry and, in order to allow its free use, Yaskawa decided to abandon his rights on the word in 1982. The word has taken a wider meaning since then, and is now widely used as a technical jargon word to describe a philosophical idea in engineering technology, more than technology itself. For this wider concept of mechatronics, a number of definitions has been proposed in scientific literature, differing in the particular characteristics, which each definition is intended to emphasize. The most commonly used one emphasizes synergy: Mechatronics is synergistic integration of mechanical engineering, electronics and intelligent computer control in design and manufacture of products and processes.

The development of mechatronics has gone through three stages. The first stage corresponds to the years when this term was introduced. During this stage, technologies used in mechatronic systems developed rather independently and individually. With the beginning of the eighties, a synergistic integration of different technologies started taking place, the notable example is optoelectronics (i.e. an integration of optics and electronics). The concept of hardware/software co-design also started in those years. The third and the last stage can also be considered as the beginning of the mechatronics age since early nineties. The most notable aspect of the third stage is the increased use of computational intelligence in mechatronic products and systems. It is due to this development that we can now talk about Machine Intelligence Quotient (MIQ). Another important achievement of the third stage is the possibility of miniaturization of components; in the form of micro actuators and micro sensors (i.e. micro mechatronics).

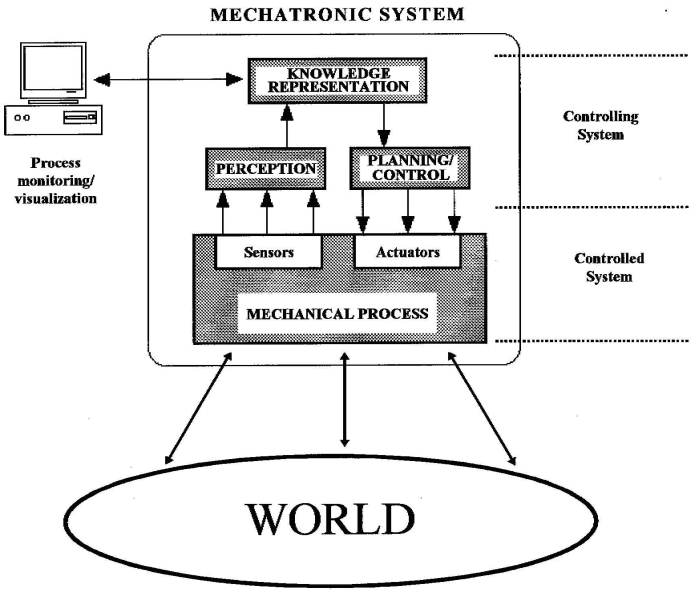

Figure 1: Mechatronic system architecture

A mechatronic system has two main components as shown in Figure 1. The controlled system is a mechanical process that is in contact with the environment by mean of all its sensors and actuators. Distinguishing features of the mechatronic system are three sub-systems of the controlling system used for perception, knowledge representation, planning and control. The intelligence is usually embedded in the planning and control sub-system. Thus, based on

information taken from the sensors, computational intelligence methods are exploited to plan a course of action that will enable the controlled system to achieve any given task. Conventional microprocessors, artificial neural networks, fuzzy logic and probabilistic reasoning are among the tools used in the sub-system for information processing and decision making.

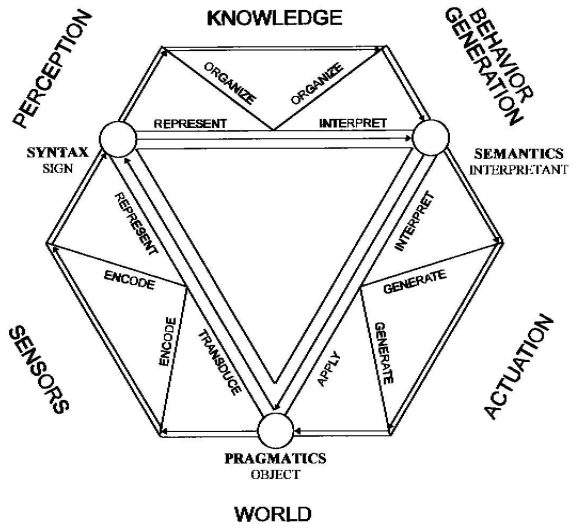

Figure 2: The functional diagram of semiotics

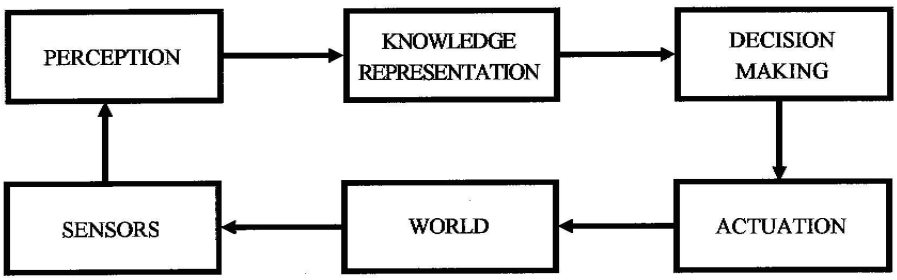

Figure 3: The six-box diagram of behavior formation

Recently, a wider concept, concept of "semiotics" is still proposed as a new paradigm of science in the 21st Century. It is defined as a theoretical field which analyzes and develops formal tools of knowledge acquisition, representation, organization, generation and enhancement, communication and utilization. The functional representation of semiotics given in Figure 2, is different, (and it is more descriptive) than of Figure 1 and, therefore, displays the link between semiotics and mechatronics. The same figure, is drawn as a six box diagram, it can be used to describe the behavior formation of living creatures and mechatronic systems. In each box of Figure 3, the same six-box diagram can be inserted, it indicates a multiresolutional hierarchy.

There are some mechatronics' definitions published in periodicals and international conferences reviews. Having studied above mentioned definitions, the following special formulation is offered.

"Mechatronics studies synergistic fusion of precise mechatronical units, electronic, electro technical and computer components for the purpose of designing and manufacturing qualita-

tively new modules, systems, machines and complexes of machines with intellectual control of their functional movements " [2].

Comments to the definition:

1. Mechatronics studies special methodological (conceptual) approach to construction of machines with qualitatively new characteristic features. It is important to emphasize, that this approach is rather universal and can be applied to machines and systems of various purposes. However, it is necessary to note, that the only way to maintain high quality of mechatronic system (MS) control is to take into account specificity of a certain operated object. It is reasonable to study mechatronics according to its specialties which have definite classes of industrial machines and processes as their subjects;
2. The definition emphasizes synergetic character of components' integration in mechatronic objects. Synergy is a mutual action taken to achieve a goal. It is very important to mention that the components of the later system not only improve each other, but being united in such a way, they bring qualitatively new properties to the system. In mechatronics all power and information flows are directed to the only one goal - to perform a set operated movement;
3. Integrated mechatronic components are always chosen at the designing stage, necessary engineering and technological support are provided at manufacturing and applying stages. It explains a considerable difference between mechatronics and traditional machines, when a user has to combine various mechanical, electronic and information-operating devices from different producers into one system at his own discretion;
4. Methods of parallel designing (concurrent engineering methods) serve as methodological basis for mechatronic systems development. At traditional designing of machine with computer control consecutive design of mechanical, electronic, sensor and computer parts of the system is carried out before choosing interface blocks. The paradigm of parallel designing consists of simultaneous and interconnected synthesis of all system's components;
5. The main objects that mechatronics studies are: mechatronic modules that, as a rule, move on one operated coordinate, sophisticated systems of modular architecture are assembled from such modules as if these were functional cubes;
6. According to the definition, mechatronic systems are intended to perform a set movement. Qualitative criteria of MS movement performance are problem-focused, i.e., defined by statement of a certain applied task. Specificity of automated mechanical engineering tasks consists in moving a target part of working body of the technological machine (e.g., a tool for machining). Thus, it is necessary to coordinate spatial MS movement together with various external processes. Regulation of force interaction between working body and the object at machining, diagnostic and control of MS critical components, control of additional technical influences (thermal, electric, electrochemical) on the object at combined methods of processing, operating auxiliaries of the complex delivery (conveyors, loading devices) and reception of signals from electro-automatic devices (valves, relay, switches) can serve as examples of such processes. Such complicated and coordinated MS movements can be called functional movements;
7. In modern MS methods of advanced intelligent control are used to secure high quality in performing complicated and precise movements. These methods base on new ideas of managing real theories, modern equipment and software and perspective approaches to synthesis of operated MS movements. Being a new branch of modern science, mechatronics doesn't have strictly stated terminology, definite bodies and classification characteristics. Revealing the sense of new principals of construction and new trends of machine development, with their movement controlled by computer, is crucial. Not a long time will elapse before all notions and definitions are formulated.

2 Principles of Mechatronic Systems Construction

When MS performs a set functional movement, the objects render revolting influences on the working body [3]. We can study, as an example of such influences, cutting forces for machining processes, contact forces and moments of forces at assembly, reactive force of the liquid jet at hydraulic cutting. We can roughly divide environmental surroundings into 2 basic classes: determ and non-determ. We can classify environmental surroundings as determined when their revolting influence parameters and characteristic features of the object can be determined beforehand so accurately that it is possible to design a mechatronic system. Some environmental surroundings are non-determined due to their nature (as extreme environmental surroundings: underground or underwater), characteristic features of technological environmental surroundings, as a rule, can be determined by means of analytic-experimental research and computer modeling methods. E.g., to estimate cutting forces at machining process series of experiments on special research installations are carried out, vibration influence parameters are measured on vibration test bench with subsequent creation of mathematical and computer models of revolting influences leaning on experimental data.

However, to organize and to carry out similar researches expensive equipments and measuring technologies are required. So, for preliminary estimation of force influences on working body at robotized barr removal from cast products it is necessary to measure actual shapes and parameters of each half-product. In such cases it is expedient to apply methods of adaptive control which allow to correct automatically the laws of MS movements in the course of operation.

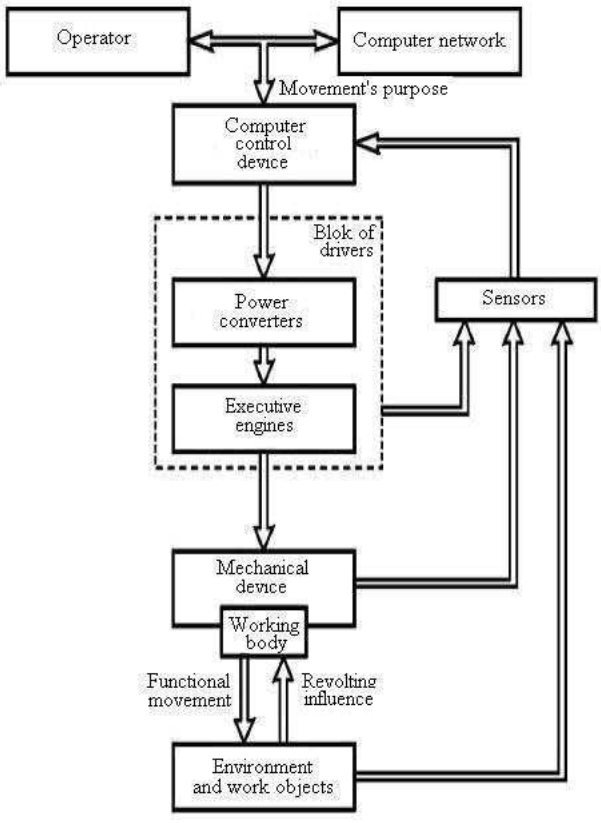

Figure 4: The functional diagram of semiotics

The structure of a traditional machine includes the following basic components: mechanical device with the working body as its final part; block of drivers with power converters and executive engines; computer control device, the top level of which is an operator or another

computer with computer network access. Sensors are used to transmit information on actual condition of machine blocks and MS movement into controling device.

Thus, these 3 obligatory parts (mechanic, electronic and computer) connected with power and informative flows is a primary characteristic feature that distinguishes mechatronic system. Electro mechanic part includes: mechanic links and transmissions, working body, electric motors, sensors and some additional electro-technical elements (brakes and couplings). Mechanical device is used to transform movements of its parts into required movement of the working body.

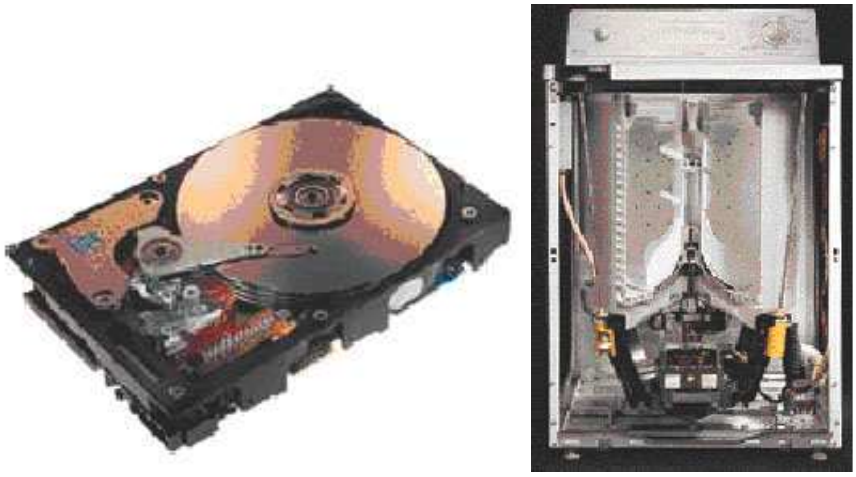

Figure 5: Examples of mechatronic systems

As it shown in Figure 5 the computer disk drive is one of the best examples of mechatronic design because it exhibits quick response, precision, and robustness. According to mechatronic principles clothes washer features a sensor-based feedback control that maintains correct water temperature no matter the load size.

The electrical part consists of micro-electronic devices, power converters and measuring circuit electronics. Sensor controls are intended to obtain data about actual conditions of environment surroundings and objects of processing, mechanical device, blocks of drivers with subsequent processing and transmitting of this information to computer control device. Top level computer and controllers of movement control are integral parts of mechatronic system.

Computer control device carries out the following basic functions:

1. Control of mechanical movement process in mechatronical module or in multi-measured system on-line with current sensor data analysis.
2. Arrangements to control MS functional movements that is to coordinate simultaneously MS mechanical movements and external processes. Discrete input/output devices are always used for external process control.
3. Interaction with operator via human-machine interface off-line and on-line interaction at the moment of MS movement.
4. Data exchange between peripheral devices, sensors and other devices of the system.

The main task of MS is to transform input information from the top level of control into purposeful mechanical movement with its control based on principle of feedback. It is notable that electric power (less often hydraulic or pneumatic) is used as intermediate power form in modern systems.

The core of mechatronic approach consists in integrating of two or more components probably of different physical nature into a uniform functional module. In other words, at the stage

of designing one interface, as a separate device, is excluded out of a traditional structure, but physical essence of transformation carried out by this module is kept.

As an ideal variant, from the user's point of view, mechatronic module, having received input information on the purpose of control, will carry out the set functional movement with desirable qualitative parameters. Hardware integration of components into uniform constructive modules should be accompanied by development of integrated software. MS software should provide direct transition from a project of the system to functional movement control of the system by means of mathematical modeling.

Application of mechatronic approach at creation of machines with computer control defines their basic advantages in comparison with traditional means of automation:

- Rather low cost owing to a high degree of integration, unification and standardization of all elements and interfaces;
- Ability to perform complicated and precise movements (of high quality) owing to application intellectual control methods;
- High reliability, durability and noise immunity;
- Constructive compactness of modules (up to miniaturization in micro machines);
- Improved overall dimension and dynamic characteristics of machines owing to simplification of kinematics' circuits;
- Opportunity to rebuild functional modules to sophisticated systems and complexes according to specific purposes of the customer.

3 Modern Trends of Mechatronic Systems Development

World production of MS is constantly increasing and expands new spheres. Today mechatronic modules and systems find wide application in the following areas [4]:

- Machine-tool construction and equipment for automation of technological processes;
- Robotics (industrial and special);
- Aviation, space and military techniques;
- Motor car construction (for example, antiblocking brake system (ABS), systems of car movement stabilization and automatic parking);
- Non-conventional vehicles (electro bicycles, cargo carriages, electro scooters, invalid carriages);
- Office equipment (for example, copy and fax machines);
- Computer facilities (for example, printers, plotters, disk drives);
- Medical equipment (rehabilitation, clinical, service);
- Home appliances (washing, sewing and other machines);
- Micro machines (for medicine, biotechnology, means of telecommunications);
- Control and measuring devices and machines;
- Photo and video equipment;
- Simulators for training of pilots and operators;
- Show-industry (sound and illumination systems).

Impetuous development of mechatronics as new scientific and technical direction in the 90ies was caused by a lot of factors among which there are the following key factors: trends of global industrial development; development of fundamental basic and mechatronic methodology (the base scientific ideas, essentially new technical and technological decisions), activity of experts in research and educational spheres.

It is possible to distinguish the following tendencies to change and key requirements of the world market in the considered area:

- Necessity for production and service of equipment according to the international system of the quality standards stated in the Standard ISO 9000;
- Internationalization of scientific and technical production market and, as a consequence;
- Necessity for active introduction of forms and methods of international engineering and putting new technologies into practice;
- Increasing role of small and average industrial enterprises in economy owing to their ability to quick and flexible reaction to changing requirements of the market;
- Rapid development of computer systems and technologies, telecommunications, especially in the countries of the European Community. Intellectualization of mechanical movement control systems and technological functions of modern machines appear as a consequence of this common tendency.

The analysis of these specified tendencies shows that it is impossible to achive a new level of the basic process equipment following traditional approaches. Development of mechatronics as interdisciplinary scientific and technical sphere besides obvious technique-technological difficulties also has a lot of new managerial and economic problems. Modern enterprises starting to develop and produce mechatronic products should solve the following fundamental problems:

- Structural integration of mechanical, electronic and information departments (which as a rule, work independently) into a uniform creative staff;
- Education and training of engineers specialized in mechatronics and managers able to organize integration and supervise work of strictly specialized experts with different qualifications;
- Integration of information technologies from various scientific and technical fields (mechanic, electronics, computer control) into a uniform toolkit to provide computer support of mechatronic problems;
- Standardization and unification of all used elements and processes at designing and manufacturing mechatronic systems.

Solution of the listed problems frequently demands that we should put an end to traditions, which were established in management before, that the average managers, who got used to solve only particular problems, should overcome their ambitions. For this reason average and small enterprises, which have flexible structure, turned out to be more prepared to start manufacturing mechatronic production.

4 Levels of Mechatronic Systems' Integration

In mechatronics it is reasonable to accept a level of integration between MS elements as a basic characteristic feature [5]. According to this feature it is possible to divide mechatronic systems taking into account their generations, if consider their presence in the market of high technology production from historical point of view.

Mechatronic modules of the first level integrate only two initial elements. Motor-reducer can serve as a typical example of this module. In this system mechanical reducer and operated engine are issued as a uniform functional element. Mechatronic systems based on these modules found wide application at development of various means of complex automation in industrial production (conveyors, rotary tables, auxiliary manipulators).

Mechatronic modules of the second level appeared in the 80ies when new for that time electronic technologies, which allowed to produce tiny gauges and electronic blocks for signal processing were being developed. Driving modules integrated with specified elements led to mechatronic modules of movement with their structure completely corresponding to the definition mentioned above, when integration of three devices that are different by their nature: mechanical, electro technical and electronic is achieved. On the basis of mechatronic modules of the given class operated power machines (turbines and generators), machine tools and industrial robots with numerical program control have been created.

Development of third generation mechatronic systems is caused by presence of rather inexpensive microprocessors and controllers produced on their base in the market. Development of these MS is directed to intellectualization of all processes taking place in mechatronic system, first of all - process of functional movement control in machines and units. New principles and technologies for precise and compact mechanical units are being developed together with new types of electric motors (first of all high moment, collector-free and linear), feedback and information gauges. Synthesis of new precise, information and measuring high technologies gives a basis for designing and producing intellectual mechatronic modules and systems.

In the future mechatronic machines and systems will be united into mechatronic complexes on the base of uniform integration platforms. The purpose of creation of such complexes is to achieve a simultaneous combination of high efficiency and flexibility of technique-technological environment due to its ability to reconfigurate, that will allow to provide competitiveness and high quality of production on the markets of the XXI century.

5 Career Paths in Mechatronics

The field of mechatronics is now widely recognized in all parts of the world [6]. Various undergraduate and graduate degree programs on mechatronic engineering are being offered by different universities.

Mechanical engineers are often at a loss to communicate and understand the issues electrical engineers and the software specialists bring up. The idea is to get rid of the uncertainties associated with electronics and computers. It means to develop people who are comfortable making the necessary trade-offs among a wide range of approaches based on the given design constraints.

With a focus on these kinds of skills, mechatronics is seen as a prime career path for mechanical engineers of the future. I believe that mechanical engineers with a mechatronics background will have a better chance of becoming managers. Mechatronics is a career for the future mechanical engineers.

Classically trained mechanical engineers will run the risk of being left out of the interesting work. These people will have much more of a chance to lead. Mechanical engineers who know some computer science are far more valuable than the computer scientists who know some mechanical engineering. Mechanical engineers have a better feel for the overall system and do a better job of making the crucial trade-offs. One possibility is that mechatronics practitioners will prototype the whole design, then, specialists in various disciplines will take over the detail design.

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