Emergence of Mechatronic Engineering and Education A Current Concept Review

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Abstract

Emergence of mechatronic engineering as a distinct professional activity which focuses on current and future trends in mechatronic engineering and the educational needs of its practitioners.

Key Words: *Mechatronics, Engineering Education, Electronics, Mechanics*

1. INTRODUCTION

1. Technological Innovation leads to Economic Progress

Technological innovation has accounted for over one-third of the growth of the largest economy, like USA, in the world. Due to technological developments in telecommunications, computerization, the Internet, etc., and the resulting globalization of markets and the global distribution of the processes of new product realization (concept development, design, prototyping, manufacture, and servicing) has lead to economic growth of a country.

Innovation may be defined as "new way of delivering customer value [1]." Often the outcome of innovation appears in the form of a new process, product, or service. However, in many cases, the development of new services is a consequence of the availability of new processes and products e.g. the development of the Internet has resulted in a radical expansion and transformation of service industry. The new services become part of "an emerging industrial value-added structure that supplies functionality around a new basic technology system [2]." While a corporation is passing through the stage of competing mainly on the basis of superior productivity (functional capability/input) and quality, the focus is on process innovation (in addition to strategic issues related to organization, human resource development, marketing, etc.). However, as the corporation forges ahead towards competing on the basis of innovation, more attention needs to be paid to product innovation.

2. Transformation in Technological Processes and Products

Changing nature of technological processes and products is shown in Table-1. Before the invention of Faraday's laws all machines (Technological processes and products) were mechanical (M) in nature, i.e., composed essentially of mechanical units. Since mechanical units exhibit large inertia, machines of this era tended to be large, cumbersome, slow, 'uni-functional' and non-user friendly (difficult to control and maintain).

By the late 19th century, it was observed and proved experimentally that electrical energy(E1) can be transmitted and transformed much more easily than mechanical energy so all energy receiving and manipulating units inside the machine (Technological processes and products) started to be replaced by functionally comparable electrical units. As a result, machines became more compact, controllable and user-friendly.

Table-1: Changing Nature of Technological Processes and Products

Before 19th century	Mechanical Systems(M)
By the late 19th century	Electrical(E1)
By 1950	Analog Electronic valves(E2)
After 1950	Development of Transistors, Digital Electronics and Power Electronics(E3)
Second half of 20th century	Development of ICs, Microprocessors, Embedded system(C)
Recent development	PLC, Micro controller, Robot, FMS

A technological transformation occurred with the advent of analog electronic (E2) valves in the earlier half of the last century. This transformation accelerated after the 1950s owing to the development of transistors, digital electronics and power electronics (E3). Wherever possible, electrical functional units were replaced by such electronic units so as to attain several orders superior performance in terms of size, controllability and user-friendliness. The synergistic combination of E1, E2 and E3 technologies may be collectively referred to as E technologies (electrical/electronic technologies).

The second half of the last century saw dramatic changes in technological processes and products like development of digital computational units (computers): general purpose integrated chips (IC), application specific ICs (ASIC), microprocessors (µp) etc. These functional units are now so small in size (miniaturized) that they can be embedded within the functional units. Such units will be referred to as belonging to C technology. Indeed much of the recent progress in industrial automation (Programmable Logic Controllers, Microcontrollers, Robotics and particularly the FMS: flexible manufacturing systems [3]) owes a lot to the emergence of mechatronic engineering.

3. The Emergence of Mechatronic Engineering

The synergistic combination of M, E, and C technologies eventually led to processes and products that could not even be contemplated before [4-7] while attaining unprecedented levels of performance. (Table-2)

Table-2: Some types of mechatronic products[4-7]

Type	Example
Transducers and Measuring Instrumentation	Ultrasonic receiver, Electronic scale
Processing machines	Turning and Machining Centres,Bonding machines
Industrial handlers	Robots, Component insertion machines
Drive mechanisms	CD Players,Printers, Disk drives
Interface devices	Keyboards

Benefits of Mechatronic Engineering [4-7]

1. Fast response time(e.g. Sevo-motion controller Camera)
2. Better wear and tear(e.g. Electronic ignition)
3. Easier maintenance and spare part replacement(e.g. Washing machine)
4. Memory and intelligence capabilities(e.g. Programmable controllers)
5. Shortened set up time(e.g. Computer Numerical Control (CNC)machines)
6. Data Processing and Automation(e.g. CNC Machines and PLC)
7. User friendliness(e.g. Photocopier)
8. Enhanced accuracy(e.g. Electronic callipers)

Many modern products use embedded computers (computer-on-a-chip) to provide hitherto unattained functionalities exclusively through mechanical means. One may also exploit the ability of a computer to be programmed at will to add new functionalities. For instance, we can create “smart” products by programming the computer on the basis of fuzzy logic or by making the computer behave like an artificial neural net (ANN). Thus computer technology offers an opportunity for endless product innovation. Mechatronic egineering is the emerging discipline that supports the development of this class of technological processes and products.

4. Defining Mechatronic Engineering

Since mechatronic engineering is an emerging discipline, it is not surprising that its definition is still under development. Among the more popular definitions is the one composed by the Industrial Research and Development Advisory Committee of the European Community: Mechatronics is "a synergistic combination of precision mechanical engineering, electronic [read computer] control and systems thinking in the design of products and manufacturing processes [5]."

While the above definition seems to be acceptable in the short term, several simplistic views or, even, misconceptions continue to prevail. Two examples are:

- Mechatronics is *"the application of microelectronics in mechanical engineering"*.
- Mechatronics is *"a combination of mechanical engineering, electronic control and systems engineering in the design of products and processes."*

  While these views are acceptable from a limited viewpoint, it is useful to clarify and/or elaborate upon them. Mechatronics does not warrant recognition as a distinct discipline if it were to be viewed merely as a summation, union or intersection of mechanical, electronic and computer principles. Basically Mechatronics is a competetive solution in terms of M, E and C.
- There must always be a design goal that is mechanical in nature. Hence, designing a voltmeter is not a mechatronic activity although the casing of the voltmeter is mechanical in nature. The mechatronic activity needed is dictated by this "mechanical" goal. This goal is often expressed as a set of performance variables that need to be controlled (constrained within limits or optimized). Hence control engineering (especially, motion control) is central to mechatronic engineering.
- The design solution is invariably a system. A system is a set of interacting elements satisfying a specified goal. In the case of a mechatronic solution, the elements can be of mechanical, electronic (including electrical elements and computational elements), or software types. The interactions (signals passed) can be of analog (continuous) or digital (intermittent).

Mechatronics is NOT about finding ANY solution to the given problem. Its aim is to produce a competitive solution. Typically, there exist a range of solutions to a given design problem. Often, a purely mechanical solution is feasible. If this is the "best " solution, it does not fall within the domain of mechatronics. Mechatronic design invariably involves tradeoffs between the advantages of alternative mechanical, electronic, and software solutions at the sub-unit level. Experience shows that an M-solution is usually inferior to a competing E-solution which; in turn, is inferior to a C-solution (Note that M-elements have large inertia, electrons have very little, and "bits " none.). Hence, the hallmark of mechatronic engineering is the conscious effort to progressively substitute M-solutions by E-solutions and, in turn, E-solutions by C-solutions.

5. Mechtronic Education

A lot of educational initiatives have been taken to focus on mechatronics Engineering education. Following the several technological developments in different streams of engineering and synergy of integration of different fields to achieve the competitive solution has emerged the new course in engineering as mechatronics engineering.

It was noted in [8] that mechatronic design

- is a complex and open ended activity requiring refinement of creativity and experience through application;

- is often a group activity in industrial practice;
- is a combination of art and science;
- requires a broad overview of market needs and business goals, and manufacturing technology."
- These considerations had led the designers to adopt the following curricular strategy.
- Recognize that control engineering (especially motion control) is a core activity.
- Develop a broad understanding of the interactions among design, manufacturing and design management.
- Take advantage of computer aided design and analysis (CAE) software in order to enable students to undertake more substantial design tasks.
- Develop the skills in technical communication required by all engineers.
- To develop a syllabus to cater the needs of academia, industries and self employment.
- An outline of the curricular structure following the above principles is as under:
- Mathematics
- Mechanics
- Technical Communication Skills
- CAD
- Computer
- Microprocessors and micro controllers
- PLC/SCADA
- Pneumatics and hydraulics
- Mechanical design
- Motion control
- Material science
- Mechatronics processes and products
- Team based design products(projects)
- Sensors and transducers
- Signal processing
- Control system
- Electrical and Electronics

Future Trends, Challenges and Limitations in Mechatronic Engineering

By definition, automation is the replacement of human labor and technology is (just) a bag of tools that come in the form of hardware and/or software. A tool is something that assists in performing existing tasks better or enables new tasks to be performed. In other words, it somehow replaces human labor, i.e., automates the task. Thus progress in technology (through mechatronics, or otherwise) is synonymous to automation.

Human activity can broadly be divided into two categories: individual or collective (social). Individual activities may be purely mental or combined with physical activity. Irrespective of whether it is reflexive or reflective [9], any human physical act requires effort at five levels:

(i) Setting the goal (a purely mental activity).

(ii) Sensing the environment (through the sensory organs eyes, ears, skin, tongue, and nose).

(iii) Communicating the sensory signals to the central neural processor called the brain.

(iv) Fusing the signals to recognize patterns of interest and output the command signals to human limbs.

(v) Performing the physical task using limbs (actuators).

A remarkable human ability is to learn from the results obtained from past acts so as to perform better when executing similar tasks in the future. This learning ability provides human beings with the ability to act as autonomous units. A further ability lies in communicating with other human beings so as to undertake collective tasks.

The above description of human abilities provides a basis for understanding and trends in mechatronics. Note that task (v)actuation, task (ii)signal communication and task (iv) signal processing and decision making have already been enabled (at least in part) by M, E, and C technologies respectively.

Future Trends:

a. *Sensor Fusion*

b. *Machine Learning*

c. *Modularization*

d. *Autonomization*

e. *Miniaturization*

f. *Link to Internet*

g. *Societies of Devices*

Sensing and sensor fusion : will be the next capability to be acquired by mechatronic systems.

Already, many mechatronic units possess rudimentary sensing abilities. For instance, modern air conditioning units are able to sense air temperature and humidity through separate sensors and fuse the signals through fuzzy logic reasoning. Likewise, sensors in the form of transducers have long been used to enable feedback control in machines. Advances in high-speed microcomputers and signal processing algorithms have now opened the door for the exploitation of sensors exploiting a wide range of physical, chemical and even biological phenomena. While actuators are limited in variety, the variety of possible sensors is almost unlimited. For instance cutting forces in CNC machining and its consequences (e.g., tool fracture) can today be monitored and controlled using commercially available devices capable of sensing machining noise, machine vibrations, acoustic emission, drive motor current [10], etc. Future mechatronic engineers will have to possess deeper understanding of natural sciences so as to cope with the growing variety of sensors. And they will have to learn to fuse these sensors using such emerging techniques as fuzzy logic reasoning and artificial neural nets (ANN).

Machine learning: Intelligence means adapting to the environment and improving performance over time [11]. Within the domain of mechatronic engineering, "there has been considerable interest in learning through the use of ANN and fuzzy logic for applications in control and robotics, autonomous guided vehicles (AGV), etc., that require mainly reflective intelligence when performed by human operators and tasks, such as machine diagnostics, requiring combinations of reflexive intelligence and low level reflective intelligence [9]." This interest will continue well into the future.

Autonomization: refers to the development of the ability to survive and perform robustly while the external environment changes. With progress in sensor and learning technologies, tomorrow ‟s mechatronic devices can be expected to become progressively more autonomous. They will be able to reset their local goals autonomously under changing external environments so as to meet the broad system-level goals set by human beings.

Modularization: will be a consequence of autonomization. Mechatronic sub-units will come in modular form, i.e., with all the abilities required for local goal setting, control, and learning encapsulated within the sub-unit. Thus, in time, every mechatronic sub-unit will be self-contained and intelligent. To the mechatronic engineer, they will appear as black boxes. All (s)he has to do is to choose the right combination of sub-units and build the desired system.

Miniaturization: refers to the trend towards mechatronic units of significantly smaller size. Progress in precision engineering, newer materials (composites, diamond coatings, etc.), and nano-technologies will contribute to this development.

Links to the Internet: The Internet will become ubiquitous within the mechatronic world. Every autonomous mechatronic unit will be connected via broadband and satellite networks to the rest of the world. Each mechatronic device will be able to access the information and knowledge base available on the Internet so as to optimize its own performance. At the same time, it will be able to communicate its operational status to remote monitors. For instance, one would be able to query from ones office the refrigerator at home about its contents and receive a fairly accurate answer. Likewise, one can query a pillbox how many pills are remaining!

Societies of devices: The metaphor of society is very similar to that used by Minsky in his book „The Society of Mind [12]. He says: "Mind is made up of many smaller processes. These we'll call agents. Each mental agent by itself can only do simple things that need no mind or thought at all. Yet when we join these agents and societies in certain special ways this leads to true intelligence.” Once a mechatronic device has become autonomous, locally intelligent, and able to communicate extensively via the Internet, it can join “societies” of devices with a common purpose or interest.

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