Considerations Regarding the Process of Integration the Mechanisms in the Structure of the Mechatronic Systems

V. Maties, O. Hancu, C.-R. Rad and L. Dache

Abstract Mechatronic systems are the result of integration the modules belonging to mechanical engineering, electrical engineering and information-automation engineering. The paper presents the fundamentals of the integration process in the nature and technology, and the role of information in that process. Information is the basic component of the mechatronic technology. Mechatronic knowledge is the result of information structuring and integration. The concept of information links, information carriers, and information kinematic chains in the study of the mechanisms for mechatronics are outlined too. The modern concepts in engineering education like transdisciplinarity, complexity and integral education are detailed based on the educational potential of mechatronic platforms. The basic approaches in the field are detailed too.

Keywords Mechatronics · Mechanisms · Integration · Information · Education

1 Introduction

The evolution and development of the human society is closely related to the technology evolution. This connection is easily understandable if we take into account the fact that starting from the Stone Age technology we are now in the information technology age.

The term mechatronics was coined by Japanese in the mid-70s last century, to define the technology fusion: mechanics—electronics—informatics. Its meaning has been continually enriched as a natural consequence of the technology development and, step by step, mechatronics has become a philosophy, the science of

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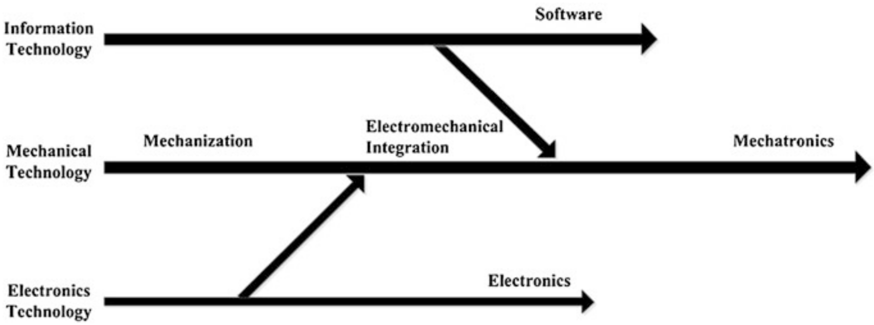

Fig. 1 Technological flow towards mechatronic integration

intelligent machines and the educational environment for integration thinking development in the knowledge based society. The flow to mechatronic integration is suggestively highlighted in the Fig. 1 (Maties et al. 2001, 2009; Nicolescu 1999; Peters et al. 1989).[1]

Traditionally, mechanical technology dealt mainly with the problems of energy and material. The progress of semiconductors, especially integrated circuits, made it possible the integration of machines and electronics in one body. However, at this stage, the system could not have intelligence yet. Next revolution began with the appearance of microcomputers. Small and cheap microprocessors have been integrated into machines, and permitted machines to think and take decisions. Then, mechanical technology has changed to mechatronics by merging information-processing functions.

Integration is mechatronics paradigm (Berian and Maties 2011; Maties et al. 2009; Nicolescu 1999) and knowledge is the result of structuring and integrating information. As integronics is the science of integration processes and hyperintegrated systems (Maties et al. 2001; Nicolescu 1999), it deals with integration levels, integration degrees, hyperintegrated systems and the benefits of integration.

Integration is not a useless process. Contrary, integration gives new possibilities to control the systems. Integration gives the possibility of association to complementary elements, the possibility of connecting, of forming cycles and networks. But integration also gives the possibility to obtain a surplus of elements, a structural redundancy. In the case of hyperintegrated systems, where everything is linked to everything, the structural redundancy results in a fantastic combinatory redundancy (human body is a very representative as a hyperintegrated system). Integration therefore gives the systems larger possibilities to maintain their identity despite the second principle of thermodynamics.

In the integration process a special role is attached to information, since elements have to recognize one another in order to be able to unite in increasingly organized systems. For this reason, each element transports the substance and

[1] http://www.complexity.ro/.

energy it consists of, structural information that can be recognized by the other elements. In this way, some elements attract and other rejects one another, giving birth to extremely varied systems.

But, if elementary particles have a spontaneous tendency to organize in systems and if each system actually is a subsystem in a larger system, it means that besides the principle of order and organization, also exists a principle of integration, intricateness and diversification of systems. If systems are integrated in larger and larger systems, these systems become more and more complex and therefore more and more diversified and differentiated. The elements or subsystems can be genetically integrated or by force integrated. An elementary particle can be captured by the atomic nucleus that will subsequently keep it by force, a force that will not allow it to leave the respective nucleus.

Besides genetic integration and integration by force, elements can also be integrated by being made dependent on the respective system. Such is, for instance, the case of ecological systems; plants and animals depend so much on one another that they cannot even live outside the respective system. Elements can often choose the system to which they will, belong as happens in social systems. That is why we can speak of integration at choice.

Finally integration is sometimes accidental. If elementary particles collide by chance, thus is engendering other elementary particles, the hazard also plays a certain part in the integration processes.

In the case of more complex systems there also appear integration subsystems, such as the nervous system, the endocrine system and the cardiovascular system that have the role of coordinating the millions of cells of the body.

In the field of mechatronic systems the approaches to get integration of the elements of the three fields of engineering are based on hardware integration and software integration.

The future trends of the technology development are: micromechatronics, nanomechatronics and biomechatronics.

As it is emphasized in the literature, mechatronics opened new horizons in all the fields of activities, because of the synergy effect. In the knowledge based society, mechatronics is the main vector of innovation and the main support to increase the work productivity in the knowledge production. Mechatronic knowledge is technological one, the knowledge to design and manufacture the intelligent products, systems and services.

In the sequel are outlined details related on the openings caused by mechatronics in the study of the mechanisms and in the field of engineering education.

2 Mechanisms in the Structure of the Mechatronic System

The basic modules integrated in the structure of the mechatronic system are shown in the Fig. 2. As we can see the structure is very similar with the structure of a control system. This could be an explanation of the fact that one of the definitions of mechatronics is: “*the science of motion control*”.

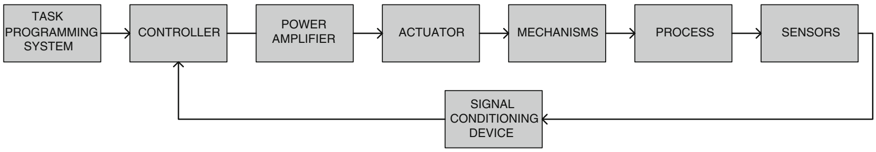

Fig. 2 The structure of a mechatronic system

The operational role of the modules integrated in the structure is: task programming system: generates the desired motions and their sequences, based on user requests or on a higher level system controller; controller: compares the desired motion with the actual motion and calculates the corrective action; Power amplifier: amplifies the corrective action to a level suitable for the actuator; actuator transforms any kind of energy into mechanical one, generating motion; mechanisms and mechanical transmissions, integrated between actuator and process, transform and adjust the motion generated by the actuator to the requirements of the process; sensors are artificial sense organs integrated in a structure of a mechatronic system and give information related on the current parameters of the process; signal conditioning device, integrates filters, amplifiers etc., and adjust signals generated by sensors to a level suitable by controller. The main feature of mechatronic systems is the dualism: energy flow-information flow (Nicolescu 1999, See footnote 1).

2.1 The Elements of the Mechatronic Technology

Long before the word mechatronics came into general use it was recognized in industry that in order to facilitate innovation and increased efficiency in manufacturing and product design, it was vital for engineers and technicians from the disciplines of mechanics and electronics to work in synergy as teams rather than independently. Competing in a globalized market requires the adaptation of modern technology to yield flexible, multifunctional products that are better, cheaper, and more intelligent than those currently on the shelf.

The importance of mechatronics is evidenced by the myriad of smart products that we take for granted in our daily lives, from the cruise control feature in our cars to advanced flight control systems and from washing machines to multifunctional precision machines.

By comparing against the conventional technology that operates mainly with material and energy, in mechatronics is added a new component, information. Obviously, making products that include more information (intelligence), their functional performance is increasing.

On the other hand, in this way the material and energy resources are preserved. But, less material and less energy means less processing, so less pollution. In this context it follows another facet of mechatronic technology: it is a no dissipative and less polluting technology.

The information is the most important element of the mechatronic technology, by comparing against material and energy. The reasons why are (Maties et al. 2009; Nicolescu 1999).

- satisfaction of the mind of human beings is caused by information;
- only information can increase added value of all things.

The value of information depends on no quantity but freshness, because the human mind always requires new stimuli. In other words, the value of material and energy depends of integration, but that of information depends of differentiation.

Mechatronic technology launched the challenge related on "sensitivity information". The commercial value of the passenger car for example does not depend on its basic function only.

It rather depends on its appeal to human senses for example, style, color, and so on. Any machine sends information to stimulate the five senses of human beings.

In particular, products that are originally designed to output sensitivity information such as musical instruments, toys, dolls, and so on have become increasingly important in the knowledge based society.

Taking into account the role of information in the structure of the technical intelligent systems it is easy to understand the importance to evaluate the quantity and the quality of information integrated in their structure.

It is important to note too, that signals are the physical meaning of information. Signals are generated by the sensors and transducers integrated in the structure of the mechatronic systems. Related on information integrated in the structure of the mechatronic systems it is defined the notion of carriers of information too. The carriers of information can be: radiant, mechanical, thermal, electrical, magnetic, chemical etc., depending on the system and the type of sensors integrated in their structure.

3 New Openings in the Study of the Mechanisms Caused by Mechatronics

Based on the concepts of mechatronics and integronics, mechanisms themself are the result of integrating kinematic elements through kinematic joints. More than, defining the driving elements in the structure of the mechanisms we have to take into account the actuators and the process (the size of the actuator is defined based on the balancing torque that acts upon the driving element). On the other hand, in order to control the motion parameters generated by the mechanism, the sensors and electronic devices integrated in the structure of the mechanisms are to be known too (Maties et al. 2009; Maties et al. 2001; Nicolescu 1999, See footnote 1).

On this way, based on the fact that the kinematic elements (rigid body) could interact trough information, the notion of information link could be defined. So that, a new definition of the kinematic joint have to be taken into account: That is: "all the possibilities of interaction between two kinematic elements". To limit the interaction can be based on mechanical contact and it is ok the conventional definition of the kinematic joint: "all the contact areas between two kinematic elements".

More than, by analogy with the definition of the conventional kinematic chain, the notion of information kinematic chain could be defined as: "an assembly of hardware and software components used to get information, to transmit information, to process and to use information in order to control the mechanisms and machines".

The concepts defined above are explicit presented by analyzing the structure and operation of an intelligent translation unit based on Lorentz actuator (Fig. 3) The intelligent translation unit is the result of integration of a Lorentz actuator with mobile inductor, sensors (position, velocity and current) and other electronic and control devices as these are shown in the Fig. 3 (Maties et al. 2001; Nicolescu 1999).

The Lorentz actuator includes the fixed part, made of the base plate, core and coil and the mobile unit made of the permanent magnets, polar plates and roles. The propulsion force is:

$$F = B \cdot I_a \cdot l = K_F \cdot I_a \tag{1}$$

where B is the induction of the magnetic field developed by the permanent magnets; I_a is the current through the coil conductor and l is the length of the coil conductor. The coil is located in the air gap of the actuator and there is no mechanical contact between mobile unit and the fixed part of the actuator.

The propulsion force is the result of the interaction of magnetic field developed by the permanent magnets and electrical field developed by the current trough the

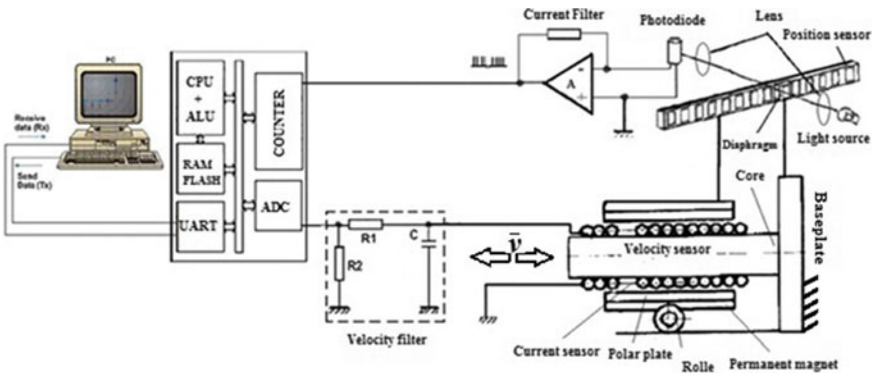

Fig. 3 The intelligent translation unit based on Lorentz actuator

coil conductor. The *information carriers* are the electrical charges that generate the current through the coil conductor. *The information kinematic chain is made of: the transducers (position, velocity and current), electronic devices, microcomputer and the specific software to control the operation of the translation unit.*

The intelligent translation units are used as translation modules in the structure of robots, in electronic technology or as positioning mechanisms. Their functional performances were proved in the applications related on positioning the magnetic heads on the disc drives.

The operation equations of the actuator are written based on the voltage balance and based on the forces balance as it follows:

$$U = I_a \cdot R_a + E \tag{2}$$

$$E = B \cdot l \cdot v \tag{3}$$

where: U—the voltage supplying the coil; I the current through the coil conductor; E—the induced voltage; l—the length of the coil conductor; v—velocity of the mobile unit.

Based on the Eqs. (2) and (3) it results:

$$U = I_a \cdot R_a + B \cdot l \cdot v \tag{4}$$

and

$$v = \frac{U}{K_F} - \frac{R_a \cdot I_a}{K_F} \tag{5}$$

Taking into account the relationship (1) we get a new relationship for the velocity of the mobile unit.

$$v = \frac{U}{K_F} - \frac{R_a \cdot F}{K_F^2} \tag{6}$$

Based on the relationship (6) we conclude that the velocity of the mobile unit can be changed by adjusting the current through the coil conductor or by adjusting the supplying voltage. Based on the balance of the forces that act upon the mobile unit we get the motion equation of the actuator:

$$F = m\frac{d^2x}{\mathrm{d}t^2} + F_r + F_f + C_V\frac{\mathrm{d}x}{\mathrm{d}t} \tag{7}$$

where: x—the displacement of the mobile unit; F_r—the resistive technological force; F_f—the friction force; C_v—friction coefficient; m—the mass of mobile unit.

The operation of the actuator is fully described by the system of equations:

$$\begin{cases} \mathrm{v} = \dfrac{\mathrm{U}}{\mathrm{K_F}} - \dfrac{R_a \cdot I_a}{K_F} \\ F = K_F \cdot I_a \\ E = K_F \cdot v \\ F - m\dfrac{d^2x}{\mathrm{d}t^2} - F_r - F_f - C_V\dfrac{\mathrm{d}x}{\mathrm{d}t} = 0 \end{cases} \quad (8)$$

The equations are the basis to study the operational phases of the translation unit integrated in an application for positioning the elements in a translation motion (Maties et al. 2001; Nicolescu 1999).

As it is easy to undertand the complexity is the basic feature of the modern cyber-phisical systems. For designing and manufacturing that systems a trans-disciplinary education is necessary. Some details in the field are outlined in the next chapter.

4 Mechatronics, Complexity and Engineering Education

English theoretical physicist Stephen Hawking, told that the 21st century will belong to complexity (See footnote 1). The complexity is closely related to the idea of non-separability, which "seems to be a fundamental principle of all that is profound in the world" (Berian and Maties 2011, See footnote 1). Consequently, research and education of the future must be shaped by the force lines of complexity and non-separability.

In other words, "intrusion of complex and transdisciplinary thinking in structures, programs and areas of influence of the University, will enable the progress towards its mission forgotten today—the study of universality". Emphasis is provided by B. Nicolescu, founding president of the International Center for Transdisciplinary Research and Studies, Paris (Nicolescu 1999). In (Berian and Maties 2011) it is shown that, in mechatronics, complexity is a thematic concept, as defined by Holton, which gives the depth of mechatronics identity, which is a trans-thematic one. The identity of a subject to be taught can be: disciplinary (mathematics, physics, chemistry etc.), thematic (system theory-based on the concept of system) and trans-thematic (based on the complexity concept) (Berian and Maties 2011).

Mechatronic platforms are complex technical systems which integrate in their structure elements of mechanical engineering (mechanisms, mechanical transmissions, etc.), electrical—electronic engineering elements (actuators, sensors, microcontrollers, filters, amplifiers, etc.) and control science—computer science elements. So that they are the basic infrastructure for learning transdisciplinarity, in order to stimulate creativity and growth of labor productivity in the mechatronic knowledge production. Mechatronic knowledge is a technological one, or knowledge about how to manufacture intelligent products, systems and services

(Kajitani 1992; Maties et al. 2001). Taking into account the trans-thematic identity of mechatronics, mechatronic knowledge is transdisciplinary one.

Learning transdisciplinarity is a major need in the knowledge based society. Integral education ensures the achievement of this objective. The concept is introduced in (Bahman 2011; Berian and Maties 2011; Nicolescu 1999) and brings into attention educational and technological approaches where the subject participate in the educational process with his whole being (mind, emotions and psychic). Thus, modern and interactive educational technologies will be based on hexagonal model for mechatronic integral education, developed in (Berian and Maties 2011).

The mechatronic approaches are very knowledge intensive (Fig. 4). They combine kinematics and dynamics, material technology, control engineering, information technology, micro technology etc.

Furthermore, mechatronic solutions are applicable in many others sectors that are of significant importance to the welfare of the citizens, such as healthcare and transport.

The power of mechatronics approach can only be fully deployed if vast amounts of knowledge and expertise are correctly combined and canalized. Integration is therefore the key issue in the mechatronic discipline. Integration means, among others, the establishment of research teams beyond the borders of specific

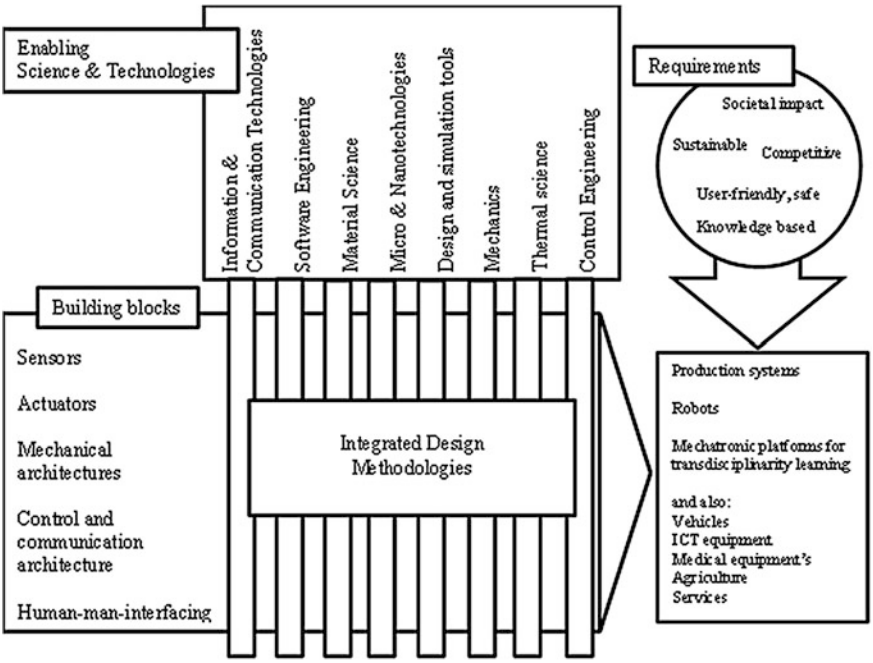

Fig. 4 The complexity concept as basis for trans-thematic identity of mechatronics

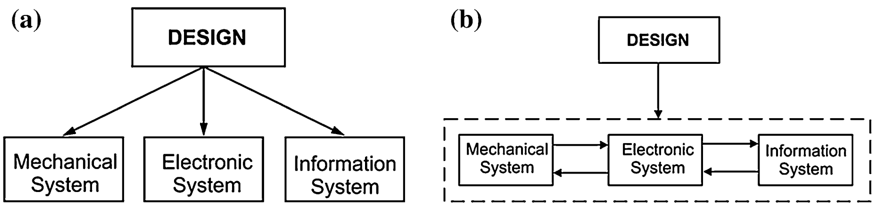

Fig. 5 Traditional approach versus mechatronic approach in engineering design

projects, existing institute or companies, having a transdisciplinary approach. Integration also means establishing the mechanisms that enable the joint management of these research teams. Integration of research resources is therefore a major undertaking.

For engineering practice mechatronic philosophy marked the jump from traditional engineering (sequential) to simultaneous or concurrent engineering (parallel).

In the Fig. 5a is presented the traditional approach and in Fig. 5b the mechatronic approach. In traditional approach, control is "attached" to the system, while in mechatronic design it is "integrated".

5 Conclusion

The development of the knowledge based society and of the mechatronics as a technology to support such a society is a historical necessity. A long of the four decades since the word mechatronics was patented by Yaskawa Electric Cp. in Japan, the content of the word improved continuously as a result of the technology development. Step by step mechatronics became: philosophy, science of intelligent machines and educational environment for transdisciplinarity learning in the knowledge based society. The basic elements of the mechatronic technology are:material, energy and information. Mechatronics opend new horizons in all the fields of activities, based on the synergy effect. Flexibility is the main feature of the mechatronic systems, caused by integrating in theirs structure of the information links. Based on the information as the main component of the mechatronic technology the notions of information link, information carriers and information kinematic chains in the study of the mechanisms are defined. The mechatronic paradigm is integration and its identity is trans-thematic one. So, based on the hexagonal model for mechatronic integral education, the mechatronic platform are very efficient tools for transdisciplinarity learning, in order to stimulate initiative and creativity.

References

Bahman AKS (2011) Integral education: founding vision and principles, integral review—a transdisciplinary and transcultural. J New Thought Res Praxis 7(1):4–10

Berian S, Maties V (2011), Transdisciplinarity and Mechatronics, Curtea Veche Publishing, Bucharest, Romania, ISBN 978-606-588-199-0 (in romanian language)

Kajitani M (1992) What has brought mechatronics into existence in Japan? In: Proceedings of the 1st France-Japan congress of mechatronics, Besancon, France

Maties V, et al (2009) Mechatronic platforms for education and research, Todesco Publishing, Cluj-Napoca, Romania, ISBN 978-973-7695-79-6 (in romanian language)

Maties V et al (2001) Mechatronic technology and education. Todesco Publishing, Cluj-Napoca, Romania, ISBN 973-8198-05-4 (in romanian language)

Nicolescu B (1999) Transdisciplinarity. manifest. Polirom Publishing, Iasi, Romania, ISBN 873-683-234-1 (in romanian language)

Peters J, Van Brussel H (1989) Mechatronic revolution and engineering education. Euro J Mech Eng 34(1):5–8