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MODELING AS AN IMPORTANT PHASE IN THE PROCESS OF MECHATRONIC SYSTEMS DESIGN[6]

Gordana Janevska
"St Kliment Ohridski" University – Bitola
Faculty of Technical Sciences – Bitola
Makedonska falanga 33, 7000 Bitola, Republic of Macedonia
gordana.janevska@tfb.uklo.edu.mk

Abstract

Mechatronics is the synergistic combination of mechanical engineering, electronics, control engineering, and computers, all integrated through the design process. As a design philosophy, mechatronics serves as an integrating approach to engineering design. A mechatronic design of product relies heavily on system sensing and component modeling and simulation to establish the optimal design across mechanical and electronic domain when subject to specific cost and performance constraints.

The key to success in mechatronic systems design is a balance between modeling (analyzing skills) and experimentation (hardware implementation skills). Modeling is an important stage in the process of mechatronic systems design. A physical model can be developed by using engineering judgment and simplifying assumptions. Through modeling an engineer can assess the integrated design concepts early at the beginning of the design process.

Key words **–** Mechatronics; Mechatronic Systems Design; Modeling

INTRODUCTION

The progress in the area of microchip and computer technology allows bridging the gap between traditional engineering across domains of

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[6] review scientific paper

electronics, control and mechanical engineering. Mechatronics appears as a response to increased industry demand for engineers capable to work across the discipline boundaries of electronics, control and mechanical engineering, engineers able to identify and use appropriate combination of technologies for optimal solutions to contemporary pretty complex engineering problems.

Mechanical systems produce motions or transfer forces or torques. The analog controllers have been used for many years for controlling the positions, speeds, or forces. Digital electronic applications allow performing of many more functions. Now a development can be observed that the mechanical systems, the actuators, the sensors, and the microelectronics are integrated in a way to forming one unit. This integration of mechanics, electronics and information technology actually leads to mechatronic systems.

The word *mechatronics* as a composition of "*mecha*" from mechanics and "*tronics*" from electronics was first used in 1969 by Tetsuro Mori, an engineer at the Yaskawa Company, to describe a system composed of mechanical and electronic components that is governed by an embedded system. The meaning of this word continuously evolves after the original definition. Today, the word *mechatronics* has come to mean the interdisciplinary field of engineering sciences which is a symbiosis of mechanical engineering, electrical engineering, electronics and computer science (computer control systems). Namely, the problems in engineering today are getting harder, wider and deeper. They are multidisciplinary and require a multidisciplinary engineering systems approach to solve them.

Most people define mechatronics only in terms of what components are included in the system and/or how the mechanical functions are realized by using computer software. Such a definition gives the impression that it is just a collection of the existing aspects of science and technology which include mechanisms, actuators, electronics, control systems, computer technology, micro-machines, etc., and has no original content as a technology. The definition that mechatronics is simply a combination of different technologies is no longer sufficient to explain mechatronics.

Integration is the key element in mehatronic design in terms that the complexity expands from the mechanical domain to the electronic and computer software domains. One of the most suitable definitions is that the mechatronics is the synergistic integration of physical systems, sensors, actuators, electronics, controls and computers through the design process, from the very beginning of the design process, allowing complex decision making. Mechatronics is the integration of different technologies in order to get the best solution to a given technological problem. It is nothing else but a good design practice. It involves the use of modern, efficient technology to improve the characteristics of products and processes and flexibility.

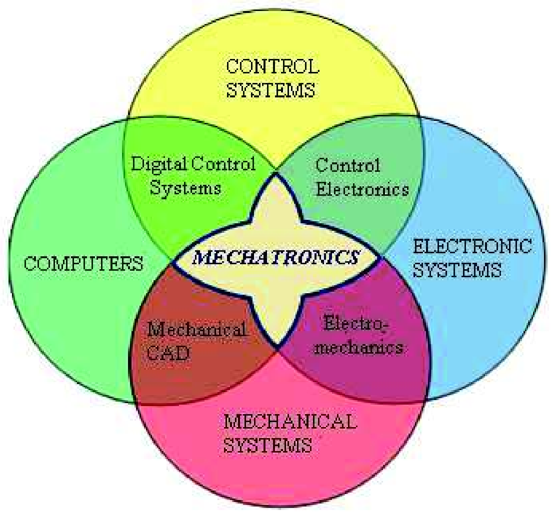


Fig.1. Mechatronics: synergism and integration during the design

As it is illustrated in Fig.1, and previously noted, mechatronics is a symbiosis of mechanical engineering, electronics, control systems, and computers. The key element in mechatronics is the integration of these areas through the design process.

MECHATRONIC SYSTEM DESIGN PROCESS

Mechatronic system design process deals with integrated and optimal design of a physical system, including sensors, actuators, electronic components, and embedded digital control system. Integration applies to both hardware components and information processing, and thus on-line and off-line. In evaluating concepts, any design-build-and-test approach must be replaced by a modeling-and-analysis approach, but this modeling is multidisciplinary and extends across domains. Each controlled physical system is not a mechatronic system, as control can be just added in the process of sequential design. In a real mechatronic approach the optimal choice is done in terms of implementation of the design specifications in the different domains. Mechatronic system design requires simultaneous optimization of the system as a whole.

The mechatronics design process, Fig. 2., consists of three phases:

- modeling and simulation;
- prototyping;
- deployment, i.e. transforming in operational state.

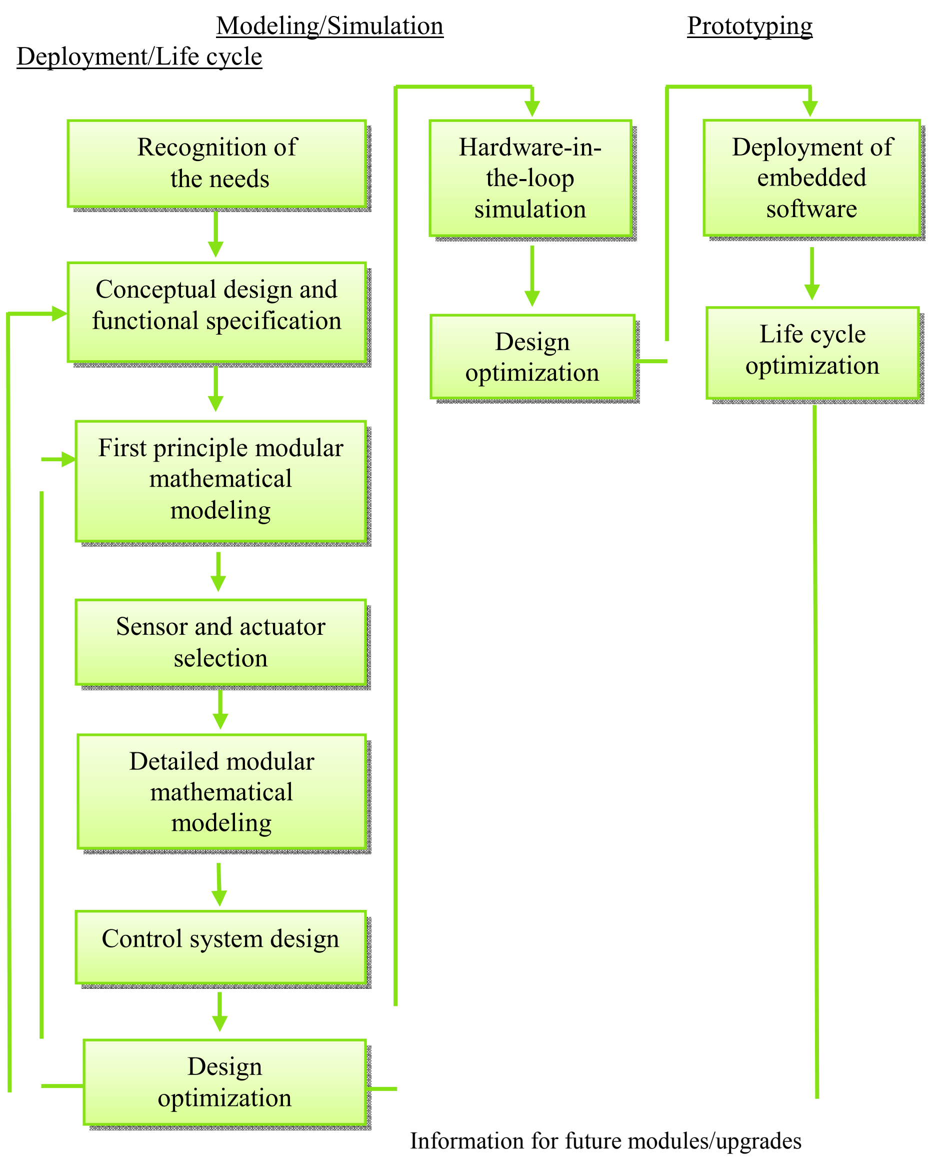


Fig.2. Mechatronics Design Process

There are some industrial normative and guidelines related to mechatronic system design process. The latest and probably the broadest guidelines developed by the German Association of Engineers (VDI) in 2002 and revised in May 2004 are given in VDI 2206 - Design methodology for mechatronic systems. In the VDI 2206 guidelines, basic elements of the design methodology for mechatronic systems are:

- the general cycle of problem solving on the micro-level,
- the V model as a macro-cycle,
- predefined process modules for handling recurrent working steps during the design of mechatronic systems

The main objective of VDI 2206 - Design methodology for mechatronic systems is to provide a systematic way of designing mechatronic systems in cross-domain.

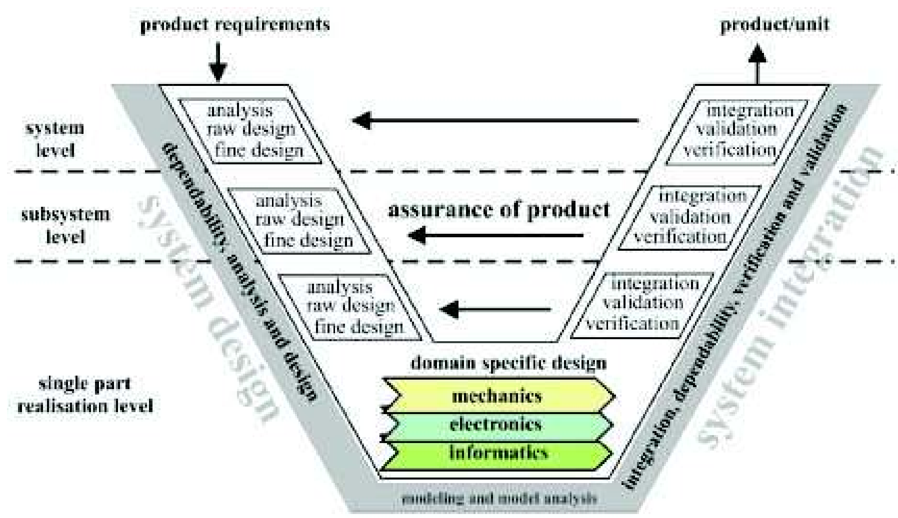


Fig.3. V model as a macro-cycle

In mechatronics, the balance is of great importance. The key to success in mechatronic systems design is a balance between two sets of skills:

- modeling (physical and mathematical), analysis, and control design (analog and digital) of dynamic systems;

- experimental validation of models and analysis, and understanding the key issues in the area of hardware implementation of designs.

MODELING AS AN ESSENTIAL ELEMENT IN DESIGNING MECHATRONIC SYSTEM

It is very rarely that the blank sheet of paper be a start point in designing. The designs usually result from improving of an existing system, from innovative combination of existing systems, or from the application of new technology or new knowledge to an existing system. In all this, the knowledge and understanding of existing systems are of the great importance, and modeling is essential to that understanding. Apart from providing a true understanding of the behavior of physical systems, on which the performance improvement is actually based, modeling also allows evaluation of integrated design concepts even in the design process without need to build and test physical components of each one. Modeling is perhaps one of the most important activities in the mechatronic systems design.

Modeling and model analysis as a stage in mechatronic systems design process aims developing a system models, as well as investigation the system properties with these models and computer aided simulation tools.

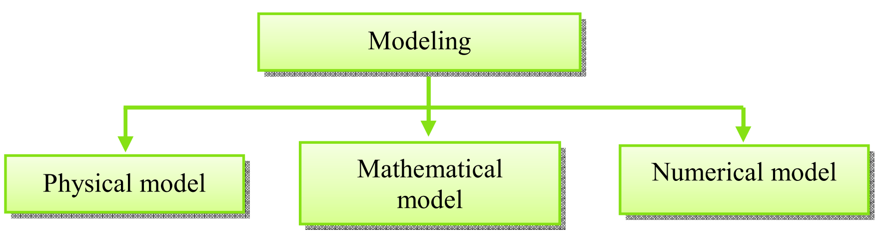


Fig.4. Process of Modeling

The development of the **physical model** is an important step in the process, but unfortunately, it is the least understood. The simplifying assumptions and engineering judgment has been used to develop physical model, which is a piece of reality and it is not an actual hardware, but an approximation of the actual system covering the essential elements of real system as extensive as it is required by the need for the model.

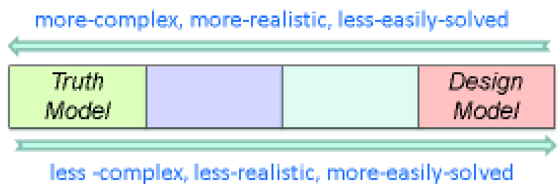


Fig.5. Hierarchy of models, depending on the particular need for model

The challenges to physical modeling are enormous, regarding that the dynamic behavior of many physical processes is quite complex. Therefore, the selection can be made from a hierarchy of physical models, ranging from the less real, less complex, more easily solved design model to more real, more complex, less easily solved truth model. The degree of complexity depends on the specific need in the considered design, such as the iterations in the system design, control system design, control design verification and physical understanding.

The unavoidable question in the modeling process is: Why are we modeling? The intelligent use of simple physical models means that when we select a simpler model rather than complex model, we are aware of what it is overlooked by the introduced assumptions for simplifying the physical system. The appropriate approximations have to be introduced during the modeling that will greatly simplify the system, but this has to be made in such way that the obtained model will still leads to quick, reasonable and accurate prediction of the system behavior.

Once a physical model has been developed, the relevant physical laws – Newton's Laws, Maxwell's Equations, Conservation of Mass and Energy, etc. – are applied to the physical model to generate the **mathematical model**, i.e. the differential equations which describe the dynamic behavior of the physical model.

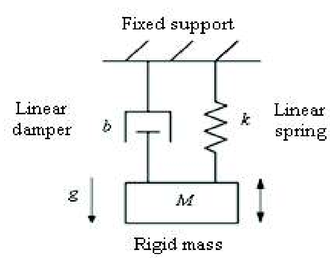
Physical system can be a real product or device, for example, computer hard drive, or it can be a basic dynamic system, for example, spring-mass mechanical system, or resistor-capacitor electrical low-pass filter. The physical system must be fully understood: how it works, what materials are used, what problem should be solved, what conditions must be met and so on. Also, when concepts are being developed as part of the design process, the physical system can be one of those concepts that need to be understood and evaluated, not by building and testing it, but through modeling, analysis, and prediction with certain experimental verification.

The spring-mass dynamic system, which is the simplest mechanical dynamic system, Fig.6, is considered as an example of a physical system. It is important to notice here that the essential characteristics (elasticity, mass, and energy loss) of a spring-mass system are present in almost every mechanical system.

The understanding of the spring-mass system behavior is the first step in the process of creation a physical model for this system. The next step is to make appropriate assumptions that simplify the system. Thus, the following approximations can be adopted:

- The support to which the spring is attached is rigid;
- The spring is determined only by its characteristic, i.e. the spring has negligible mass and energy dissipation (damping);
- The spring is ideal, i.e. there is a linear relationship between spring force and spring displacement within considered range of mass movement;
- The attached mass can be treated as a rigid body;

a)



b)

Fig.6. Spring-mass mechanical dynamic system:
a) physical system, b) physical model

- The mass moves with one degree of freedom, i.e. it moves only in the vertical plane (translational movements). Therefore, the mass can be treated as a mass concentrated at a single point (point mass);
- Energy dissipation due to friction in the system can be treated just as energy dissipation due to viscous friction, i.e. it can be covered by dumper which, like a spring, also can be treated as ideal and has a linear behavior;
- All parameters (mass, spring constant, coefficient of viscous friction) are constant.

With these assumptions, the physical model schematically shown in Fig.6b is obtained for the considered physical system.

The most realistic physical model of a dynamic system leads to a *mathematical model* represented by behavior equations that are nonlinear, partial differential equations with time-varying and space-varying parameters. These equations are the most difficult to solve. The introduction of simplifying assumptions leads to such a physical model of a dynamic system, which is less realistic and its *mathematical model* is represented by behavior equations that are linear, ordinary differential equations with constant coefficients. These equations are easier to solve.

This dilemma of choosing between easy-to-manipulate and realistic model has been very nicely formulated by Pindyck back in 1972: "*Our preoccupation with linear time-invariant systems is not a reflection of a belief in a linear time-invariant real world, but instead a reflection of the present state of the art of describing the real world* ".

CONCLUSION

The process of mechatronic systems design provides an environment that is rich with numerical and graphical analysis and with the design tools, which stimulate innovation and collaboration within the design team.

In the process of mechatronic systems design, through system modeling and simulation, it has become easier to: understand the behavior of the proposed concept for the system; optimization of the parameters of the system that is designed; development of optimal control algorithms, either local or supervisory; testing of control algorithms for different scenarios; as well as testing the produced controller with a simulated version of the plant running in real-time (hardware-in-the-loop testing) before it has been connected to the real plant.

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