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USING AN INTEGRATIVE MODEL FOR MECHATRONIC DESIGN EDUCATION

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ABSTRACT
Mechatronics may be defined as an interdisciplinary field of engineering science, which characterizes the interconnections between mechanical engineering, electrical engineering and computer science such that these interconnections are the basis for designing successful products. One key aspect for successful design is the application of adequate methods and tools. On this account the presented educational model helps in teaching young mechatronic design engineers.

Keywords: product development process, mechatronic design education, integrative model

1 INTRODUCTION

Mechatronics can be considered to be an integrative discipline utilizing the technologies of mechanical engineering, electrical engineering/electronics and information technology in order to provide enhanced products, processes and systems [1]. The role of mechatronic subsystems will increase dramatically in future product development processes. Two of the main driving forces for this development are the improved functionality of mechatronic products with increased complexity and the resulting demand for modularization ([1], [2]).
On the one hand, the high integration in design allows realizing a great variety of required functions in one single mechatronic system, which often results in an ideal tailor-made design with respect to the given requirements, but it has disadvantages when this system should be reused for other design tasks. On the other hand there is the demand for modularity in product design, which means, that a mechatronic module should be exploitable repeatedly for many different tasks.
In a mechatronic design process especially the phase of conceptual design is crucial. Here the functional interactions between domain-specific subsystems are determined and have to be investigated carefully therefore. This implies that during the phases of conceptual and preliminary design the designer should be able to quickly and accurately evaluate the system performance due to design changes in the mechanical part as well as in the other parts (electronics, software etc.). With a mechatronic approach, mechanics and control aspects are studied simultaneously.
Within the scope of this paper, a model is presented which helps the design engineer to develop an appropriate structure of the mechatronic system. On this account the propagate model helps also in teaching young mechatronic design engineers.
The paper gives an overview about several design situations, for example the analyzing of interactions in design teams. Typically, the mechatronic design team consists of several engineers, possibly organized in domain-specific teams. Each engineer is an

expert for some of the subsystems or disciplines that make up the system design, with responsibilities for all the design aspects related to the subsystems under consideration. In teaching mechatronic design it is necessary to give the students some design guidelines for dealing with the different physical domains involved.

It is required to transfer the skills and techniques learnt in one specific course (e.g. mechanical engineering) other related courses (e.g. electrical engineering) and integrate them.

The objectives in mechatronic design education are:

- To understand the importance of mechatronic product development and innovation
- To teach product development as a systematic, multi-disciplinary process
- To provide an understanding of the relationship between the product and the consumer needs
- To apply product development techniques and analytical skills to projects.
- To develop project orientated and team-working skills
- To develop project management and communication skills

2 PRODUCT DEVELOPMENT AND MECHATRONIC DESIGN PROCESS

2.1 Mechatronic Design

Mechatronic systems are multidisciplinary products, therefore the knowledge required for developing such products/systems is broad. Currently, there is a lack of integrated development methodologies and tools for mechatronic products. Traditionally, mechanical engineers develop their design with strong emphasis on the geometric domain, the electrical components are engineered in an electrical domain. These steps result in a given equipment for automation and control of the system which is usually developed in an automation department represented more or less by software engineers. All these persons have different views on mechatronic products.

When designing a mechatronic system, it is possible to design the mechanical equipment, before any of the control system design has been initiated. An obvious drawback of this sequential approach is the lack of compatibility between the subsystems which results in additional efforts and costs to meet the specifications of the total system. Another drawback of this approach is that during the design process decisions have to be made about whether to use a mechatronical or just a mechanical solution. Designers have to coordinate between mechanical and electronic solutions. Without coordination between the different domains it is difficult to find a suitable solution. Not only the selection of materials and the knowledge about process constraints with respect to the geometric possibilities of parts play a role, but also the selection of completely different working principles from different domains. It is clear that designers need help for their increasingly complex and multidisciplinary task. It is necessary to support the designers to rapidly review alternative solutions during the design process and facilitate the correct choice.

One of the key-issues in the development of modern mechatronic systems is the strict integration of mechanical, control, electrical and electronic aspects from the beginning of the earliest design phases on. Some of these aspects about Mechatronic Design are also discussed by VDI-2206 [2], Isermann [3] or Bishop [4].

2.2 Organization of Design Processes

Many researchers have carefully analyzed the different steps during the design process [5, 6]. The development / design process is usually structured into four sub-processes

[7], namely the phases of Problem Definition, Conceptual Design, Preliminary Design and Detailed Design. The explosion of information technologies during the last years has also revolutionized the design process. So the information technologies provide new tools for communication in the development process. Databases and CAD-systems provide reproducible, “error-free” archives and design baselines of the product instantly accessible for all authorized design engineers. Information technologies also provide a useful window into the team and design process for analysis and tuning of the design activities. These new technologies, of course, require specific training.

Another important aspect is the consideration of technical and social interaction inside design teams. For mechatronic projects, the experience in the interdisciplinary nature of the design process plays an important role. Conceptual Design is one of the most important phases during product development, as the main parameters, properties and costs of the solution and consequently also the main portions of success of the new product are fixed here. When a system (overall system, sub-system or component) is designed totally new, the conceptual design process leading to the design concept for the system is usually a mentally intensive and challenging work. As this step fixes the main portion of success of the new product, it should be done by excellent engineers. The determination of the product’s overall function, of its most important sub-functions (main functions) and their interactions lead to a functional structure. During this design phase, principal solutions with a structure of realizable modules should be established.

In this stage the cooperation between the several design engineers is of vital importance for the success of the design process. Typically, the mechatronic design team consists of several engineers, possibly organized in domain-specific teams. Each engineer is an expert for some of the subsystems or disciplines that make up the system design, with responsibilities for all the design aspects related to the subsystems under consideration.

3 DESCRIPTION OF THE INTEGRATIVE MODEL FOR MECHATRONIC DESIGN EDUCATION

A principal role of designers in each stage of product development is to make decisions. If the engineers have no overall overview over the multidisciplinary system, consultations of the experts of the other fields are necessary. Decisions help to bridge the gap between an idea and reality. In general, decisions are controlled by information from many sources (and disciplines). As a rule, we have to accept that in most cases dealing with design not all of the information is available required to arrive at a fully correct decision. Some of the information may be hard, that is, based on scientific principles and some information may be soft, that is, based in the designer's judgment and experience.

In our case we promote a special model description for mechatronic systems in education of mechatronic design. For the achievement of all aspects discussed in the previous chapters, we need a method, which helps the design engineer to analyze and evaluate functional requirements and design parameters of possible solutions. Our mechatronic pillar design model was developed to assist the engineer especially in mechatronic design tasks by structuring of the design process and by increasing transparency.

A mechatronic module utilizes several domains (disciplines) of mechatronics (e.g. mechanics, automatic control techniques etc.) merging the respective domain specific components (according to [8]). That means that a mechatronic module can only be decomposed into domain-specific (non-mechatronic) components, but not into other mechatronic modules or mechatronic system components. A mechatronic module therefore designates a mechatronic sub-system at the lowest hierarchical level of a mechatronic system and is indivisible within the set of mechatronic sub-systems. With the mechatronic pillar design model all couplings between the several mechatronic disciplines (domain pillars) can be described in a superior data platform. Each model pillar characterizes a domain-specific sub-component, which is structured into several hierarchical levels corresponding to the proceeding degree of detailing.

The above model description has the following implications:

- Only the first (highest) level has an interface to the other pillars (compare with encapsulated modelling) via the mechatronic coupling level.
- All couplings between the model pillars (e.g. design parameters and requirement parameters affecting multiple disciplines) are captured and described at the mechatronic coupling level.

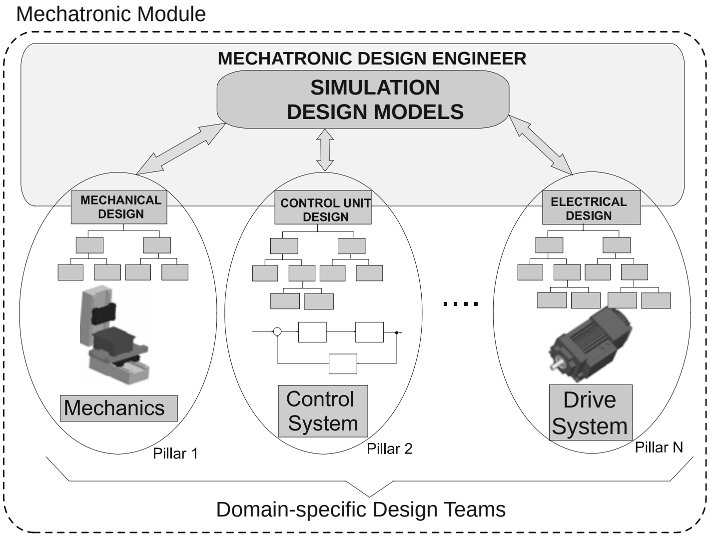

Figure 1 Mechatronic Design Model

The model structure has to be adapted if additional couplings between domain-specific components are detected during a design iteration (design, analysis, integration, performance check etc.). This is also true if new or additional domains (pillars in the model) come into consideration.

4 CONSIDERATIONS AND EXPERIENCES

The presented concept was applied the authors in several lectures and practical course. A short summary about these consideration and experiences will be given in this chapter.

4.1 Background Mechatronics at Johannes Kepler University of Linz

Education as well as research activities of the Mechatronics group in Linz are guided by a very general view on mechatronics. Linz is actually the place where mechatronics is taught in its full width with nearly equal shares of mechanical and electrical engineering as well as computer science from the very beginning of the study. It is a five year curriculum and was started in 1990. Right now 700 students are enrolled in the program and every year there are about 120 newcomers. We emphasize to impart a profound understanding of the basic engineering sciences and train their application to practical problems. Eleven chairs are devoted explicitly to mechatronics. In education and partly also in research they are supported by the departments for computer science, mathematics and physics.

One of the eleven chairs is represented by the Institute for CA-Methods in Mechanical Engineering, where the authors are working. Our key aspects of activities in research and teaching are CAx-Methods for Mechatronic System (CAD, FEM, CAM,…), Integration of Mechatronics into Product Development Processes and Machine Dynamics.

The institute offers courses on mechatronic design, where the education model descript above is used. The topics of these electives are Conceptual design of mechatronic systems , Ideas finding Methods, Computer Aided Design (CAD), Computer Aided Manufacturing (CAD-CAM), Selected Applications of the Method of Finite Elements for Mechatronic Design, Project seminar Mechatronic Design and Master Thesis.

4.2 Usage of CAx-Systems in Mechatronic Design Education

The main goal of designing is to conceive an optimal product under the given circumstances in the shortest time and at minimum costs. Computer support to the design process is necessary for the quality of the design solution and to reduce time to market. The outcome of these aspects is the motivation of including the usage of CAx-Systems in the education process. Especially in the case of mechatronic design the handling of such systems during the several phases of the product development process is one key point.

The calculation and simulation tools, which are used in the product development process, can be classified into three categories according to the different design stages, namely tools for dimensioning, verification and optimization.

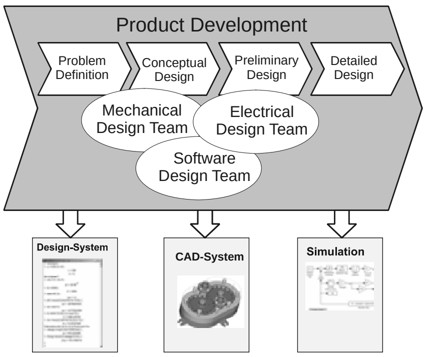

Figure 2 CAx-Systems

Coupling of modelling and simulation tools from the different areas of mechatronics is one of the most important points to decrease the time of product development. CAx-systems were developed to a large extent to optimally perform specific tasks. CAD was originally developed to define the geometry of a part, CAM to define the manufacturing process, CAE/FEM for analysis and evaluation of product properties. The data generated and applied by these different systems are mutually coupled, therefore efficient data exchange and interaction between the CAx-systems involved is a key-point in today’s innovation processes. In this context it is necessary to describe the complex structure and hierarchy of the product, which finally allows the use of product data management functions for simultaneous engineering (Figure 3). So the learning process of mechatronic engineer is affected by the interaction and integration in design (see e.g. [9, 10]).

5 CONCLUSION AND OUTLOOK

Mechatronic systems are multidisciplinary products, therefore the knowledge required for developing such products and systems is broad. Currently, there is a lack of integrated development methodologies and tools for mechatronic products. Integration of approaches and computer aided tools will be key aspects to accelerate product development processes in the future. This paper presents an integrative model for teaching mechatronic design.

Different aspects, such as design team activities, definition of mechatronic design models with their hierarchical structure, computer aided support of the design tasks, are considered for the education point of view.

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