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INTERDISCIPLINARY METHODS AND TOOLS FOR THE DESIGN OF MECHATRONIC PRODUCTS

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1. Introduction

The mechanical engineering scene has increasingly incorporated electrics and electronics for the control of mechanical systems. Mechatronic Engineering is an integrating discipline that combines the fundamentals of mechanical engineering, electrical engineering, and computer science in order to meet the requirements of the industry involved in automation, robotics and related areas. With the growing importance of design automation and an increasing need for integrating engineering disciplines, new methods and tools for this interdisciplinary design should be provided.
In this paper, the meaning of design methodology will be discussed as fundamentals for engineering work. Computer aided methods and tools which have been developed at the Department of Computer Integrated Design (DiK) will be presented. A prototype implementation shows how these methods and tools could enhance engineering tasks in mechatronic product development.

2. Design Methods

Design methods are independent from any product technology or industrial discipline. They represents the fundamentals for engineering technical systems. The *Verein Deutscher Ingenieure* (VDI, Association of German Engineers) has set up a large number of handbooks and best practices, which should provide guidelines and a common understanding for the design of products. In the field of mechanical engineering the guideline “VDI 2221: Development of technical systems” is very recognized in German industry. On the other hand, electrical engineers speak a different language and have adopted a method provided by the guideline “VDI/VDE 2422: Development of electrical and electromechanical systems”. Today, the strong demand for the integration of different engineering methods promotes the definition of a new VDI-guideline for the development of mechatronic systems, which is VDI 2206. The definition phase of this guideline was launched in 2000 and the rollout will probably be in this year.
An integrated method for the development of mechatronic systems has been researched at the Department of Computer Integrated Design and is under evaluation within different projects. This method is based on work of [Ehrlenspiel 1995], [Haberfellner 1997], [Hubka 1984], and [Pahl and Beitz 1997] but incorporates additionally principles from Computer Aided Engineering (CAE). In detail, an integrated method for the development of mechatronic systems should start with the definition of general product functions (*Funktionsstruktur*), followed by the conception of work principles (*Wirkstrukturen, Prinzipstrukturen*) and finally detailed by engineers from different disciplines, who have different views on a common mechatronic system. Different methods specialised on individual disciplines are necessary to support modelling, analysis and simulation as well as optimisation which of mechatronic systems.

It is important to perform a mechatronic design from a common point of view in order to integrate technologies and engineers from different disciplines. The structure of functions of a technical system is discipline independent and a common language to designers of any discipline. Furthermore, the idea of how the intended product will work is described using general product functions after requirement engineering and a first defined system specification. Therefore product functions represent central pieces of an engineering puzzle especially for the development of mechatronic products.
In order to realise main functions and sub functions of mechatronic systems, mechanical components, hydraulic components, electrical or electronical components, computer hardware and software are combined and tailored to certain design requirements. During the design of mechatronic systems these components needs to be modelled and analysed using CAx systems. Hahn splits up the modelling of mechatronic systems in design of kinematic functions, design of dynamic functions, and design of mechatronic functions [Hahn-99]. The function-based design methodology suggests modelling processes according to CAx , e.g. Computer Aided Requirement Engineering (CARM), Computer Aided Styling (CAS), Mechanical Computer Aided Design (MCAD), Electrical Computer Aided Design (ECAD), Digital Mock-Up (DMU), Finite Element Analysis (FEA), Multi Body System Simulation (MBS), Computer Aided Controller Design (CACD), Mechatronic System Simulation, etc. Figure 1 shows the function-based design methodology for interdisciplinary product development of mechatronic systems.

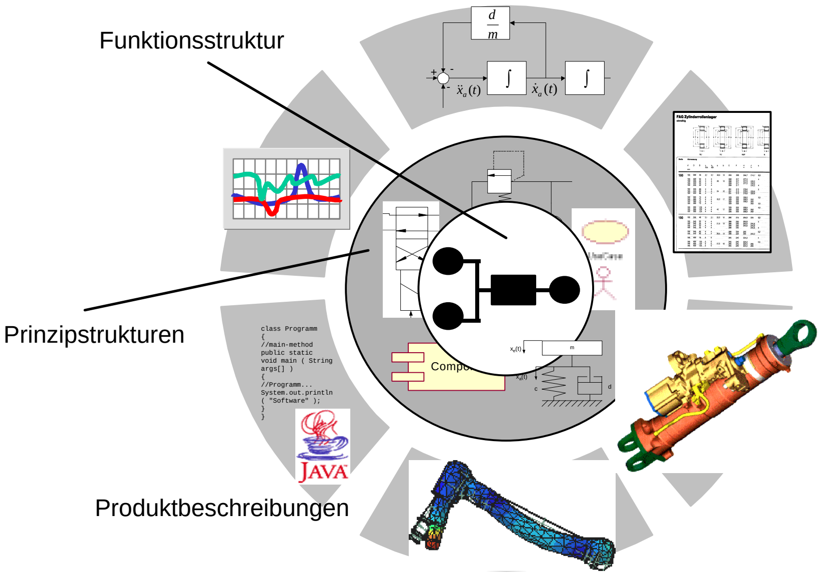

Figure 1. Function-based Design Methodology for Mechatronic Systems

3. Interdisciplinary Computer Aided Methods

CAx systems are designed for specific engineering tasks only. For example, CAS systems are designated for generating free form lines and surfaces of a product, CAD systems are used mainly for solid modelling and some basic free form modelling issues, FEA systems are analysing finite elements of a system concerning stress, electromagnetic interferences or fluid dynamics, MBS is used for dynamics, and CACD software assist engineers in order to parameterise controllers and check the holistic product behaviour and system performance. In order to integrate the computer aided modelling and analysing process, computer aided methods and tools need to be synchronised.
Computer aided methods could be divided into three levels, which are data pre-processing, data processing, and data post-processing. Data pre-processing means that input data need to be prepared for the specific design task assisted by post-processor system. For example, before generating a solid model based on a product shape, the geometric data of a CAS system must be parameterised in order to modify the geometry model with CAD systems afterwards. Data processing represents the main

task in product modelling or analysis, where the user is assisted by CAx systems. For example, solid modelling with CAD systems or building models with blocks, and sub blocks using a block diagram in order to simulate system performance. Depending on the next process step in computer aided engineering process chains, a product model needs to be prepared for CAx systems (data post-processing). The output of a computer aided method is a product model (CAx model) which could be differentially in a virtual product development process. Several requirements depending on the upcoming task are asking for a specific product model quality. This fact could be described as *Design for CAx*. Geometry models need to be reduced for FEM, restructured for MBS, simplified for packaging or interference checking with DMU tools, etc.
In order to reduce time for data pre-processing and data post-processing, different computer aided methods and processes must be configured and tailored to their main application. In one case, a method for CAS and CAD was set up in order to transfer product model data and to support frequent model changes of CAS or CAD models. The result of this method, which is called Bounded-Solid-Method, is a fully parameterised geometry model. The freeform modelling process assisted by CAS systems delivers models, which are used as a bounded solid models in order to trim or create solid models in CAD systems. The resulting solid model is a parametric geometry model constrained by free form features. If there is a change in free form geometry, the solid model will adapt this model changes automatically. Figure 2 illustrates the described computer aided method for styling and design.

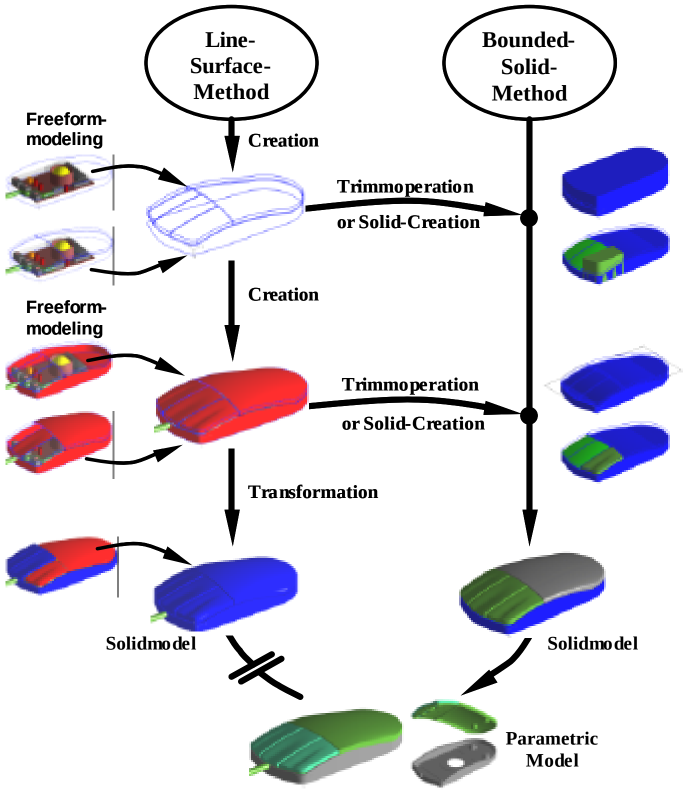

Figure 2. Bounded-Solid-Method

Besides the mentioned CAS/CAD method computer aided methods for FEA, MBS, DMU, Rapid Prototyping (RP), Computer Aided Animation (CAA) and their integration have been researched.

4. A Supportive Technology for the Design of Mechatronic Systems

In the area of modelling and simulation tools for the design of mechatronic systems, it is very important to support engineers with expressive and easy to handle tools. In consequence, engineers could concentrate on the modelling of the problem domain as well as the analysis of simulation results and are not distracted by the use of complex modelling methods or software systems. The main task is to capture and represent knowledge from the real system or the intended product in the simulated system or virtual product. In particular, for many CAx models it is necessary to incorporate all aspects of product's properties, functions, and behaviour. The main challenge in mechatronic engineering is the integration of legacy systems with flexible product data models and communication mechanisms. All CAx models must be synchronisable and the ability of parallelisation of modelling processes is of crucial importance in terms of Simultaneous Engineering and Concurrent Design. Once a model has been developed, its data correctness, consistency, and redundancy-free storage become necessary. Exchange and sharing of data become an important issue.

The aim of different research projects at DiK was to implement processes and tools for an integrated and continuous product development of mechatronic systems [Anderl, Gräb, Kleiner 2001] For example, a process chain for the design of aircraft actuators comprising different development tools, which have previously been used in an isolated way, has been set up with an industrial partner. The result was a data exchange environment, which extends the engineering data management system [Anderl, Fröhlich and Kleiner 2000]. The system's purpose is to support and control the transfer of data between different CAx systems. The basic functions are needed for exchanging model parameters between engineering tools, such as CAD and CAE systems, are supported by a underlying PDM system.

Against this background, new questions and requirements concerning the integration of CAx models for the development of mechatronic systems concerning the integration of CAx models for the design of mechatronic products arise. The most significant requirement arise because of a lack of methodology in mechatronic product development: In order to support the function based design methodology the parameter transfer is only a first step. Model structure information related to product functions must be shared as well in order to support the collaboration of engineers from different design disciplines. This has led to the implementation of a new software prototype called *X-Portal*. The architecture of the X-Portal is illustrated in figure 3.

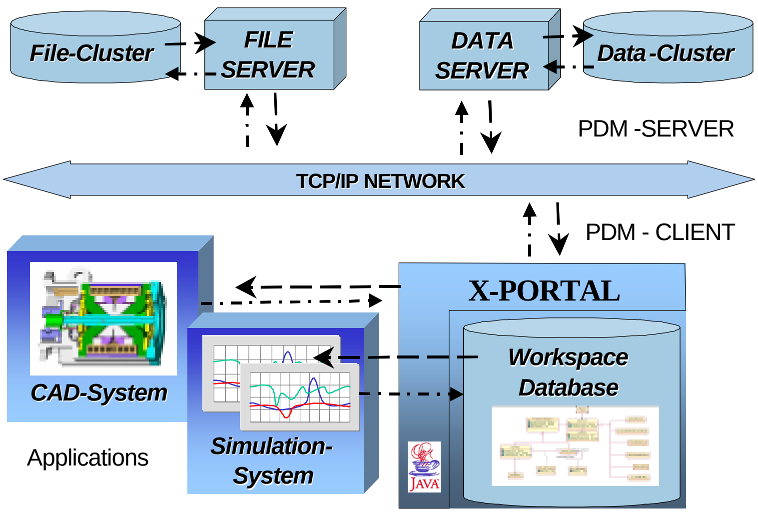

Figure 3. System Architecture of X-Portal

The X-Portal allows the exchange and sharing of parameters of arbitrary CAx models and model structures including model element hierarchies and relationships. In order to connect these CAx models and support data transfer, different model trees as well as a function tree are available. Using drag and drop mechanisms, CAx model structures and product function structures represented by trees could be analysed and connected in a logical way. Data exchange processes based on the XML technology allow the import and export of related model data between different CAx systems. Hence, interdisciplinary views on product models (e.g. requirements, functions, components) are possible and general data exchange between product models of a mechatronic systems is supported. The software system initiates the connection between different CAx systems (e.g. CAD system PRO/Engineer, CAE system MATRIXx/SystemBuild) and imports CAx models, which are stored in a PDM system. The user analyses those CAx models corresponding to the function structure of the system and exports or imports data which is needed for modelling issues.

The main components of X-Portal are

- a neutral product data model based on ISO 10303 (STEP) and extended by parametrics (data representation1 schema),
- interface components to CAx Systems (CAx Connectors) and a PDM System,
- a graphical user interface for the analysis and synthesis of CAx models and interaction.

Figure 4 shows the user interface of the X-Portal. The structure browser on the left hand side represents the function structure of an actuator and the browser on the right hand side contains a view on the CAD model of the same actuator. In this case the use of a filter option is helpful in order to reduce information and to focus on the relevant data only. For example, the CAD model and its properties could be analysed and prepared for data exchange reasons using the model context menu or editing the properties of the CAD model. Relationships between model nodes and elements of a function structure (logical links) could be defined by just drag and drop one object onto a designated object.

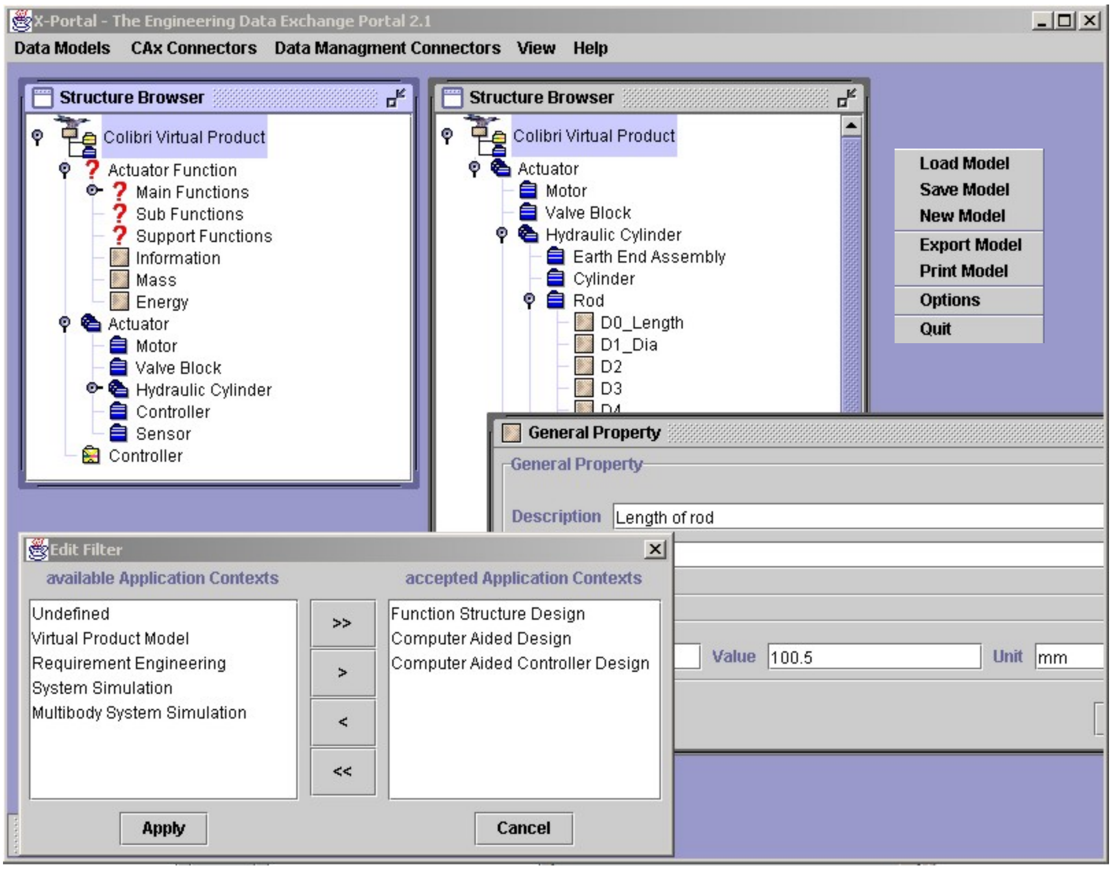

Figure 4. Screenshot of X-Portal

5. Conclusion

A prerequisite for a successful integration and an efficient use of model parameter and structure exchange mechanisms is to build or restructure CAx models according to a common pattern. In this paper the idea of the function based design approach was discussed. The function structure was used as a framework for the application of computer aided methods and especially for the mapping of interdisciplinary between different applications and models.

First experiences with the developed X-Portal from research show, that it is important to integrate CAx models for the design of mechatronic products based on a common design methodology.

References

Anderl, R., Fröhlich, A.., Kleiner, S., "Data Management of Mechatronic Products", Proceedings 6th International Conference on Concurrent Enterprising, Toulouse, pp. 213-221, 2000.

Anderl, R., Gräb,R., Kleiner, S, „Paramtrische Integrationals Grundlage für die virtuelle Produktentwicklung", Industrie Management June 2001, 2001, pp. 64-73

Ehrlenspiel, K.., "Integrierte Produktentwicklkung", Carl Hanser, München, 1995

Haberfellner, R., „Systems Engineering: Methodik und Praxis", 9. Auflage, Verlag Industrieller Organisation, Zürich, 1997.

Hahn, M., „OMD – Ein Objektmodell für den Mechatronikentwurf", Mechatronic Laboratorium Paderborn, University Paderborn, 1999.

Hubka, V., "Theorie Technischer Systeme", 2 Auflage, Springer, Heidelberg, 1984.

Pahl, G., Beitz, W., "Konstruktionslehre: Methoden und Anwendung", 4. Auflage, Springer, Berlin, 1997.

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