Title:
An Approach to Model-based Parametric Design of Mechatronic Systems

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Introduction:

In today's industrial plant design sector, as in all other industries, cost and time pressure are steadily increasing. The reasons are the general acceleration of economic processes and the resulting price pressure due to globalization. Diverging customer requirements often make it impossible to standardize whole plants [1]. Standardization is therefore applicable only to machines or at the component level. A high number of new product developments (unique pieces) increases not only the risk of error, but also development time and staff requirements for the plant builder. At the same time, the market requires a significant amount of variation within a period of five years. The changes in economic growth along with the different periods in the product life cycle result in fluctuations in demand. A plant builder can react to such fluctuations by enlisting the support of engineering partners and leasing personal during peak periods or by reducing permanent staff during weak market periods. The latter, however, leads inevitably to large know-how losses and higher training costs. The development of unique products differs from the design of serial products in that its development process is limited by the shorter project completion time given. Several processes need to overlap or run simultaneously. Moreover, the cost-saving potential of optimization is significantly smaller because of the lower quantity produced. All these factors increase the need for tools that improve efficiency in product development. Most companies embrace the advantages of 3D CAD. Some add different PLM systems [2] to support development and production. Standardization with advantages such as consistent quality and low price is also applied increasingly often in industrial plant construction. The benefits of standardization are greatest if the company owns the required manufacturing facilities or at least has fixed manufacturing partners. However, this is usually not the case, because owning such facilities is usually only economical for the production of core components and entails the disadvantage of limited flexibility. Furthermore, the acceptance of standard products is generally rather low as, among other reasons, customers want to integrate their experience into the development. Another approach to reducing the costs and execution time of a project without losing flexibility is to use parametric models. In contrast to standardization, the cost reduction due to parameterization is significant even for low product quantities. To minimize costs, the plant manufacturer must solve the problem of finding a balance between standardization and parameterization, considering the boundary conditions and the strategy of the company.

Main Idea:

The product development process using parametric models can be divided into three phases: project definition (concept, basic design), module design (detail design) and system integration [3]. In the first phase, after establishing a rough concept for the solution, the parameterization concept can be chosen and the control parameters of the product with their possible ranges of values can be initially determined. This forms the basis for creating the module structure and interfaces. At this point, assemblies with known components can be classified, followed by the rough design of the control assembly and the main assembly. The second phase consists of the detail design of the modules, including optimization and standardization using parametrical adjustments. The third phase includes functional testing of the model, any property-ensuring measures, such as stress analysis and collision analysis, and the resulting adaptations. For reasonable allocation of modules (components) to the defined classification system, aspects such as manufacturing, engineering, delivery time, execution time, quality and customer satisfaction must be considered. As previously mentioned, the ultimate goal of parameterization and standardization is a direct or indirect reduction of costs while retaining quality. Of course, the return of investments has to be positive. To ensure this, the potential for reducing costs and the expense for the improvement must initially be estimated and then compared. The first step is to determine the dependency of the current component on the current parameter in the predefined value range. If the dependency is not given or is so small that it can be neglected, the component can be preliminary classified as identical with the current parameter. The next question is whether standardization is possible. If not, the component can be classified as "customized". However, if it is possible, the question arises of whether defining the component as “identical” with the current parameter is possible and profitable. In case it is not, the question remains of whether it is possible to perform the function in the given space with a similar but scaled geometry. In this case, it is again only a question of profitability whether a discrete ("similar") or a continuous ("parametric") scaling is to be used. The following factors are relevant to determining the profitability of using identical components: costs, delivery time of manufactured parts, execution time and risk. The task of the case study was to parameterize a grid winch system called “Driving Axle” and to build an automatic product configurator for different customer requirements in order to improve development efficiency. Because of the numerous parameters and their relations, the parameterization of many present products, particularly of complex mechatronic systems, is difficult to accomplish. Therefore, a suitable parameterization concept is developed in this work. First, the entire system is divided into groups according to a function-based analysis. After analyzing the internal and external relations, the groups will be defined as “active”, “semi-active” or “passive”. This characterization significantly facilitates the determination and definition of a suitable parameter structure and sequence of parameterization. It is thought as one of the best solutions for implementing parameterized modeling in small and midsize companies. The relations between the customer requirements and the function groups auf the system can be classified as direct and indirect dependencies, which are described by arithmetic and geometric formulas. Figure 1 describes these interactions in more detail for the case study “Driving Axle”. An arithmetic relation is a unidirectional relation, because we have defined inputs and outputs. Geometric relations are bidirectional, because they consider the interaction between two parts. The “sequence” of parameterization is very important. Based on the relations, three types of functional groups are defined: active, semi-active and passive groups.

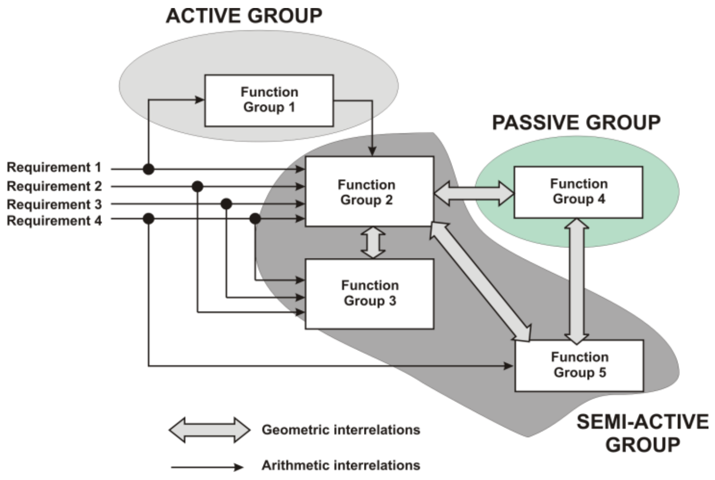

Fig. 1: Relations between Requirements and function groups.

Conclusions:

In this contribution, we have presented an approach to model-based parametric design of mechatronic systems. Our approach has two important advantages: First, a variety of system structures can be established and evaluated, and second a hierarchy of model parameters can be defined. Hierarchical models are essential tools in handling the increased complexity of such integrated design tasks. As the levels of detail specified during the design process increase, the models become increasingly detailed, resulting in a hierarchy of models and the parameters that describe them. We are confident that this point in particular plays a major role in the success of mechatronic products on the market.

References:

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