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# Approach for an Integrated Model-Based Design of Intelligent Dynamic Systems Using Solution and System Knowledge

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**Abstract**

In the design process of intelligent technical systems, simultaneous and concurrent engineering is generally encouraged on the one hand, while on the other hand cooperation and coordination of the involved disciplines is required. In multidisciplinary system development, 1) a common understanding of the objective is of vital importance for the system's success and 2) the combined artifacts of the different disciplines need to be analyzed before the system is built. In this paper, we address these issues and present an approach for an integrated model-based design process, which facilitates the use of solution and system knowledge and reduces the huge effort for building and maintaining the required simulation models. To illustrate this, we use the application example of two cooperating delta robots.

The system knowledge constitutes the basis for concurrent design in the involved disciplines, all of which provide and expand certain aspects. To analyze the domain-specific dynamic behavior of the subsystems and their components, multiple dynamic behavior models are developed in different levels of detail and domains. However, in order to analyze the complex interactions and dependencies between them, integrated models of the whole system are needed, which fit the varying modeling objectives and analysis goals. Certainly, the manual process of building up such models and maintaining consistency between all the artifacts entails great effort. To improve this, we present the concept of a Multifunctional Model Client (MMC).



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## 1. Introduction and Problem Analysis

The design process of intelligent dynamic systems is typically characterized by close collaborations and many cross-dependencies of different domains/disciplines. Searching for new and innovative solutions and in order to improve the functionality, designers aim at using synergy effects. However, modern cyber-physical systems (CPS) not only require many of these interactions but are also expected to feature high dynamics.

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Thus, the increasing complexity can no longer be met with the current design methods very often. This is due to many challenges that arise from the lack of methods, processes, information or tools. In this paper we attempt to address aspects of the following subset (see also [1]):

- clarification of goals and requirements,
- early model-based testing of required characteristics,
- exchange of design models and data,
- cooperative work and information exchange among the design engineers,
- simultaneous consideration of designs from different disciplines,
- lack of tools and methods supporting multi-disciplinary design.

To cope with these issues, we 1) use and connect models of many different kinds, 2) re-use solutions of former developments and 3) make system knowledge available for the designers. At first, we use on the specification technique CONSENS [2] and the SysML4CONSENS profile [3] to build a discipline-spanning system model that formalizes a conjoint view on the system. Here, we focus on obtaining and modeling technical requirements as well as assuring consistency between requirements and other modeling constructs. To achieve this, a hierarchical interpretation of requirements is used. Additionally, the structure of active principles displays the system elements, their interfaces and interactions.

To add comfort to the analysis of multidisciplinary mechatronic systems, a concept of a Multifunctional Model Client (MMC) is developed (cf. [4]). The MMC serves three main purposes: It semi-automatically configures dynamic behavior models by combining models of the components for the specific problem. Also, it is linked to the system knowledge/system model and therefore able to ensure consistency between dynamic behavior models. And lastly, it provides access to reusable models (solution knowledge) that were made available via semantic web ontologies. Thus, the designer is able to analyze the integrated system by means of the assembled simulation model. For this purpose, MMC takes the desired level of detail into account and has all component models that are currently available at its disposal.

We use the technology of Semantic Web ontologies to formalize solution and system knowledge. The idea behind the Semantic Web is to enrich information with annotations in such a way as to enable machines as well as humans to understand and correlate the content [5]. Therefore, the knowledge of experts on the subjects involved is stored resp. modeled in so called ontologies. Ontologies provide a way to describe not only information on facts but also on the semantic relationships between concepts. Also, inference rules allow logical conclusions. In contrast to mere databases, so-called reasoners will then be able to expand the explicitly stored knowledge with implicitly existent knowledge that resulted from the logical relations and rules modeled. Thus, logical errors in knowledge representation become evident. The logical consistency of the ontology can be checked. To build up ontologies, we use the W3C standard OWL 2 [6]. Here, classes, datatype properties and object properties are subdivided and defined.

In order to integrate dynamic behavior models, to manage variability of their components and to achieve consistency, we use feature modeling techniques. These techniques provide an easy, understandable, and generic way of representing the variability information, independent of a specific application domain [7].

The remainder of the paper is as follows: At first we will explain the design process in general. Subsequently, we will focus aspects, which are important in this context. Thus, Section 3 deals with deriving and modeling technical requirements and the structure of active principles. It is pointed out how these two models can be used to reduce consistency issues. In Section 4 we then explain the concept of the Multifunctional Model Client, which is particularly useful in the discipline-spanning coordination. At last we will give a conclusion and an outlook for future work.

## 2. Design Process of Intelligent Dynamic Systems

As regards the design process, we rely on existing design methodologies, mainly the VDI guideline 2206 (cf. Figure 1) and the specification technique CONSENS [2,8], which divide the development process into three main phases: the discipline-spanning conceptual design or system design, the concurrent discipline-specific