Data Management for Multidisciplinary Mechatronic Systems

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Abstract: This paper contributes to the development of computer-based support for the concept development phase of the design of mechatronic systems. The complexity of the data management aspects of the product models can be significant throughout the design process. Functional modeling concerns functional description of the design intention. Port modeling is an important aspect of the design process, especially for data management. This paper investigates the modeling capabilities of the System Modeling Language SysML for modeling the functional level interfaces of interconnection. It helps as well in the complexity reduction of the design data management.

Keywords **- Data management, functional model, SysML, mechatronic system, interface modeling.**

I. INTRODUCTION

Many types of data related to mechatronic products are created throughout their design development process, and they need to be managed. Product models are used for the support of product data management (PDM), in which all the pertinent information is accessed, stored, served, and reused by stakeholder [1]. The huge volume of data involved in product models at different level of detail throughout the design process poses a big challenge.

Computer-based tools used for the support of product data have been developed, typically, for a specific discipline such as CAx, EES (Electrical/Electronic Engineering Solutions), CASE, and PLM [2]. These tools produce data related to the product model and product structure that are incompatible with one another. Diversity of data from different disciplines offers some challenges such as the following:

1) It is difficult to show, understand, and construct the interdisciplinary and functional relationships between the different systems and components.
2) Increasing the efficiency of directing and organizing the design development process can be achieved by making use of the information extracted from product models.
3) The imprecision and incompleteness of the design requirements pose challenges in the analysis and exchange of product data.

A. Early Design Stage in the Development Process

In the early stages of the design process, the data of product models are used to describe the links, connections, and interfaces of the product elements and functions of the various domains in an abstract way. The necessity of viewing the integrated overall mechatronic system alongside its interfaces and connections between the different domains/disciplines throughout the entire design development process is vital. Also, a common language is valuable in order to enable traceability, and reasoning between the different components and functions.

B. Functional Modeling

Functional modeling provides a high-level system view specifying the functionality of the product from the product description. Functional modeling comprises specification of a model that describes the function and the functional relationships as objects and relations, facilitating the development process. Through functional product modeling, a solution-independent and abstract representation of a task to be created can be represented [3]. For this reason, functional modeling is considered when modeling at a conceptual level, where functions can be drawn from the realization of the different requirements of customers [4]. This abstraction of the basic concepts using the product function is used in many areas and is supported by suitable development tools, especially in electrical, electronic, hydraulic, pneumatic, thermal, and software development. Originally, functional modelling was not established for the support of computer-aided modeling and design, where it is considered as a model-based approach. The development of the functional model is done throughout the design process using documents only [5]. The formulation of a functional basis for the functional models is needed to proceed to model based functional design. Therefore, a contained controlled vocabulary has been developed for functional modeling in the design knowledge repository. It consists of 53 functions (in a verb form), and 45 flows (in a noun from). Each of the functions, and flows is structured in a three-level hierarchical taxonomy [6]. The most abstract forms are at the highest level, which is called the “primary class,” e.g., branch, channel, or convert for functions, and energy, material, and signal for flows.

C. System Engineering

Model-based Systems Engineering (MBSE) is a multi-disciplinary approach to help understand the context and specification to satisfy the specified customer requirements by developing system solution in response to the different needs of the stakeholders [7]. Aspects of MBSE include behavioral analysis, system architecture, requirement traceability, performance analysis, system simulation, test, and so on [8]. Numerous process models, methods and tools are available for supporting model-based development. The system is usually modeled using UML (Unified Modeling Language) and System Modeling Language (SysML). They are widely used modeling languages that support MBSE, which are provided by the Object Management Group's System Modeling Language [9].

System Modeling Language (SysML) is an extension of MBSE and can be utilized as a computational mechatronic product model. However, there is a lack of acknowledgement and practice of MBSE in industry, which indicates that there is a need for further development of MBSE with respect to usability [10]. Therefore, the following criteria need to be fulfilled:

1) The models must display the abstract mapping of the product functions, activities and components, and their dependencies. They should also provide information about the internal changes between the disciplines to aid in the development process of the product.

2) The models may be able to contain meta-model information as well, in which the traceability, and reasoning between systems, sub-systems, and components are permitted.

3) The data of the product model should participate in the advancement, guidance, and organizing of the process development models.

II. DATA MANAGEMENT IN PRODUCT MODELS

STEP, which stands for STandard for the Exchange of Product model data, is known as the ISO 10303 [11] standard. Application Protocol (AP) is a part of STEP that specifies the scope, context, and information requirements of STEP. Different parts of STEP APs are used for different engineering domains; for example, AP 203, AP 209, and AP 214 are used in mechanical design. AP 233 is used for the exchange of the product data and information in system engineering and it is used in many industries such as aerospace, automotive, and shipbuilding [11].

AP 233 defines the element of a system that interacts with other systems as a connector. The link between two connectors is defined as a connection [12]. However, no further details are given for the description of connections, and connectors. [13] integrates UML with AP 233 in order to provide more detailed information about the interface connections and connector. But this work is limited to software engineering. [1] proposes a multidisciplinary interface model to aid the multidisciplinary integration. His work provides a structural representation of the interface in order to be able to store information about the model data for future reuse of knowledge. Three aspects of the interface are defined: Type (geometry, energy, control, or data), configuration (to describe what elements are linked), and desired/undesired (weather the link creates positive or negative effect).

[5] proposes a data scheme for functional product description, where SysML model capabilities are integrated. This data scheme benefits from the abstraction level of the design and provides the information between the requirement, functional, and logical levels. However, the compatibility rules are not enforced to guarantee a correct integration. [14] develops a consistency check between the object flows of the functional model in SysML. In his work, the ports between the two systems have to match; i.e., energy to energy, material to material, or signal to signal. A detailed port description for the different object flows is not available. The present work will develop data modeling in SysML for the data management in the functional model. It will provide a detailed description of the object flows in SysML and, at the same time, guarantees compatible port matching.

III. DEVELOPMENT OF DATA MANAGEMENT FOR FUNCTIONAL DESCRIPTION OF PRODUCT MODELS

The scope of the present study is the functional product description, which is important since a functional model is the heart of the conceptual design phase of the mechatronic design process. Moreover, as this study focuses on the data exchange of the product model, the aim is to model the object flow, while the object functions are outside the scope of this work.

A. Object Flows

Object flows are defined as the input and the output of a function. They are used for the data and information exchange between different functions. [6] and [15] classified three basic flows in any design problem: Energy, Material, and Signal. These flows are specified more accurately in the form of vocabulary, and each basic flow is categorized into primary, secondary, and tertiary (or class, basic, and sub-basic). The vocabulary is used to describe the flow in a high-level of abstraction, and with of development of the flow categorization, a more accurate description can be achieved.

B. Modeling in SysML

SysML aims to provide a language that enables to capture different aspects of the information about a system in an integrated model. This would increase the communication between different aspects of the model, and it decreases the ambiguity between the designers and stockholders. Moreover, SysML has the capability for model system interfaces with different types. Interface model of SysML v1.3 retains all the capabilities from SysML v1.2 and provides additional capabilities.

Object Modeling Group (OMG) works for the development of STEP AP 233 within SysML by performing a mapping of the data construction between them.

Previous work used hierarchical structures to model the data exchange between different levels of the early stage of the development process; namely, between requirements, functional, and logical levels. Even though hierarchical structure provides a good overview of the of the system, and closes the gap and understanding between levels, it does not consider the internal data structures among each system level.

C. Integration of Object Flows in SysML for Functional Model Description

The link between functions in the functional level is performed according to the functional basis mentioned previously. For the modeling of different categories of the class flows in SysML, the development of ports are introduced next.

Ports in SysML v1.3 is represented here as the interface of functions with other functions or with the environment. Each port can be specified with a type and, therefore, is called a typed port. Three types of ports are proposed for the representation of the object flows: flow ports, full ports, and proxy ports.

Flow ports are typed by flow specifications and they are introduced here for the representation of the Energy flow class. The details of basic and sub-basic descriptions of the flow class can be contained in the flow specifications, which specify the types of flow coming in or out of a function, as shown in Fig III-1.

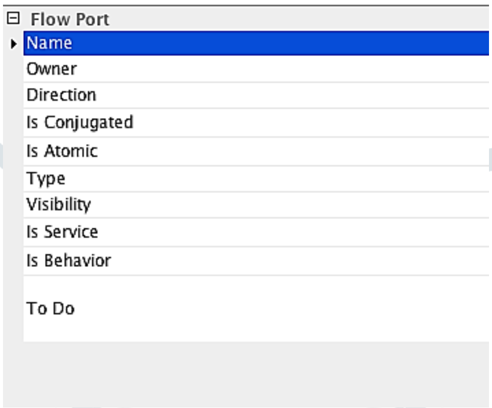

Figure I-1: Flow specification.

Full ports are typed by a block, where it is presented here for the modeling of the Material class. Full ports are used for the representation of a part of a system, in which the information of the Material class is stored inside the block.

Proxy ports are typed by an interface block. It is used for representing the Signal class as it specifies which features are accessible, and it cannot have behavior or internal parts.

D. Port Compatibility

The connection between different types of ports should be done without violating the constraints. The compatibility between ports is based on the port type, name, and direction. Proxy ports do not require a compatibility check as it can provide signal/information to all other port types.

For example, Fig III-2 shows a violation of the port name, where two materials with different names are to be transferred from a function to another.

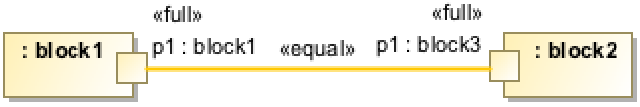

Figure I-2: An exchange of material with different names.

Another example is shown in Fig III-3, where the direction of the energy flow is now consistent.

Figure I-3: Inconsistence of flow direction.

IV. APPLICATION EXAMPLE: CONVEYOR SYSTEM

The goal of this section is to demonstrate the application of the proposed data modeling in SysML according to the defined ports and object flows. The evaluation will be limited only to the data exchange of the functional modeling.

Presentation of the Conveyor System

An electro-mechanical conveyor system falls within the category of a mechatronic system. In the present case study, such a system that is used to transport fish from the feeding station to the cutting station in a fish processing machine is considered [16] (Fig. IV-1). Conveyor systems are widely used in fish processing machines in order to provide an intermittent motion for the fish during transportation for cutting. The motion profile is planned in such a way that the cutter has sufficient time to cut the head of each fish with minimal wastage of meat, while the fish is kept stationary. Furthermore, the fish has to be held firmly during the transportation and cutting operations.

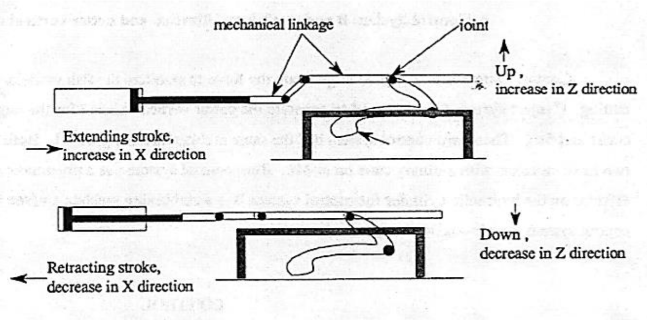

Figure I-4: The conveyor system [17].

Many considerations have to be addressed in the design of a conveyor system. In the present example, a main objective of the conveyor system design is to cut the fish head rapidly (e.g., in a cycle time of two seconds) and accurately. Also, the system has to operate under medium to light-duty load, and must have a medium to low cost.

Development of the Functional Model

The main functional requirement of the drive system is to "Produce an intermittent motion" of acceptable characteristic. The main function can be modeled as a black box with inputs and outputs. The input flows to the main function are human energy, electrical energy, and solid material. Human energy represents the energy for human interaction to turn the machine on, feed the fish at the inlet of the conveyor, and monitor the machine operation. The electrical energy includes the electrical power supply to the motors, hydraulic system, and other hardware. The solid material is the fish. There is only one output, which is solid and represents the processed fish. Subsequently, the main function of the conveyor system is decomposed into sub-functions arranged in sequential and parallel structures. At the same time, the inputs and the output should be preserved. Fig. IV-2 shows the functional structure of the "Produce intermittent motion." The functional structure offers a discipline- and solution-nature view. Electric energy is used to drive the conveyor because of the advantages of using an AC motor. They can provide low cost, stable speed, high power factor, and high reliability.

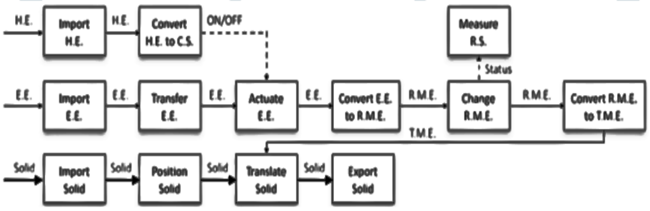

Figure I-5: The functional model of the conveyor system.

C. Functional Model Development in SysML

In order to computationally model the multidisciplinary interface for the functional description of the product model, MagicDraw [18], which is a computational software that enables the modeling language UML, and SysML that comes with extra extensions for system simulation [19], are used as the platform software for SysML modeling. Fig. IV-3 shows the functional model that was created using the Internal Block Diagram (IBD) with the functions indicated in the boxes. The ports indicate the interfaces of functions with each other and are indicated in small boxes attached to the functions. They provide the incoming and outgoing Material, Energy, and Control signal.

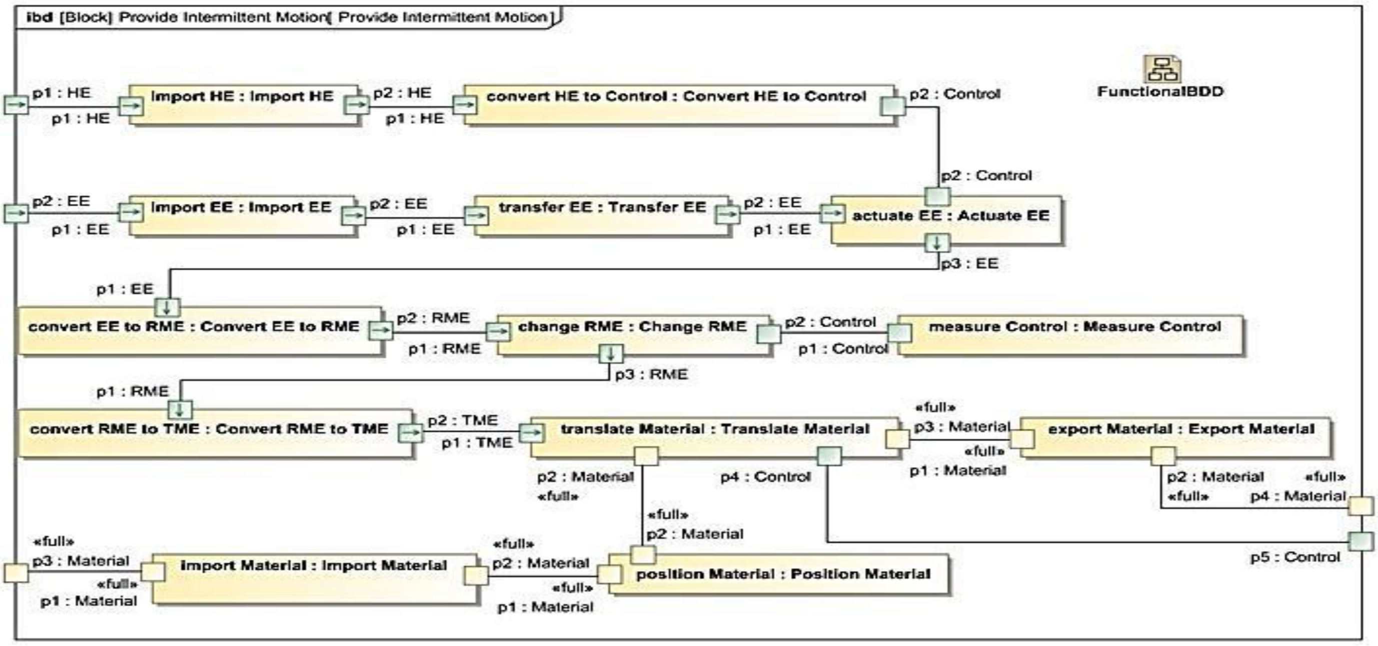

Figure I-6: Functional model in SysML.

The port type indicates the flow class. For example, the ports with an arrow indicate the Energy class. Moreover, each port is further described by additional information for the basic/secondary level of flow information.

D. Evaluation of the Developed Port Model

The SysML port syntax provides the possibility of allowing only one direction of flow and unspecified flow. Also, static semantics prevent incompatible connections between ports. Correct data exchange can be automatically checked. The current SysML port specification provides generic port modeling that can be used to represent the necessary modeling aspect of this stage, namely functional modeling.

The advantage of port modeling with graph style arrangement is that it gives a structural overview from the usability viewpoint. It is essential that port modeling can be kept free of redundancies and changes can be tracked. In addition, SysML offers much convenience since it is able to set links, and store information within the model, where the need for re-use is addressed. It, also, aids in the data management of the design, where it can provide support for paper-based functional modeling to help with the abstract description of the design.

V. CONCLUSION

This paper presented the applicability of SysML for port modeling in the functional description within the conceptual design phase. It presented a potentially formal computational port modeling approach for an integrated product model, where it can be substituted for the formal paper-based modeling approach. It can benefit from the static and dynamic consistency checking of the functional model and provides an important and relevant feedback for the designer. Also, It aids in for the data management and knowledge reuse for the later design phase.

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