Computers in Industry 76 (2016) 24–37

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Multidisciplinary interface model for design of mechatronic systems

Chen Zheng, Julien Le Duigou, Matthieu Bricogne, Benoît Eynard *

Sorbonne Universités, Université de Technologie de Compiègne, Department of Mechanical Systems Engineering, UMR CNRS 7337 Roberval, CS 60319, 60203 Compiègne Cedex, France

ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form 20 October 2015
Accepted 2 December 2015
Available online 17 December 2015

Keywords:
Mechatronic design
Product model
Multidisciplinary integration
Interfaces modelling
Systems engineering

ABSTRACT

The design of mechatronic systems is based on the integration of several disciplines, such as mechanical, electrical and software engineering. How to achieve an integrated multidisciplinary design during the development process of mechatronic systems has attracted the attention of both academia and industry. However, solutions which can fully solve this problem have not been proposed by now. The concept of multidisciplinary interface represents the logical or physical relationship integrating the components of the mechatronic system or the components with their environment. As the design of mechatronic systems is a multidisciplinary work, the multidisciplinary interface model can be considered as one of the most effective supports to aid designers for achieving the integrated multidisciplinary design during the development process. The paper presents a multidisciplinary interface model for design of mechatronic systems in order to enable the multidisciplinary integration among design team members from different disciplines. On the one hand, the proposed model ensures the consistency of interface defined by the designers. On the other hand, it helps the designers to guarantee the different components integrate correctly. The interface model including three concepts: classification, data model and compatibility rules. The multidisciplinary interface model is implemented by a case study based on a 3D measurement system.

1. Introduction

The term Mechatronics originated at the Yaskawa Corporation from the combination of mechanics and electronics. With the development of technology, the meaning of mechatronic has been broadened to include software and computation [1]. Nowadays, mechatronic systems are considered as the resulting integration of electrical/electronic systems, mechanical parts and information processing.

Design of mechatronic systems encompasses a wide range of disciplines, therefore the multidisciplinary integration has been proposed and it becomes more and more crucial for mechatronic systems [2,3]. To achieve an integrated multidisciplinary design, one kind of problems which should be overcome is described as "Design data-related problems" [4]. Such "Design data-related problems" are relevant to the edition and management of the diversity of product data from different disciplines. However, neither academia nor industry has yet provided an effective solution which can fully solve the problems in the design of mechatronic systems [5].

The paper presents a new multidisciplinary interface model to aid the designers to overcome the design data-related problems and to achieve the integrated multidisciplinary design of mechatronic systems. The concept "interface" in the considered context refers to the logical or physical relationship integrating the components of one mechatronic system or the components with their environment [6]. These multidisciplinary interfaces can be also used to indicate the collaboration of different design teams and to provide a high-level guidance for organisation and management of development process. The multidisciplinary interface model proposed in the paper includes three concepts: interface classification, interface model and interface compatibility rules. First of all, the interface classification is considered as the foundation of the multidisciplinary interface model, because it not only gives much more details of an interface, but also helps the designers to avoid the confusion by the misuse of interfaces in an early design phase of mechatronic systems [7]. Second, the product model can be used as an effective and efficient support for the design of mechatronic systems because it includes all the information that can be accessed, stored, served and reused by stakeholders [8]. The interface model will be defined as a part of dedicated product model of mechatronic systems. It not only takes

* Corresponding author. Tel.: +33 344237967.
E-mail addresses: chen.zheng@utc.fr (C. Zheng), julien.le-duigou@utc.fr (J. Le Duigou), matthieu.bricogne@utc.fr (M. Bricogne), benoit.eynard@utc.fr (B. Eynard).

http://dx.doi.org/10.1016/j.compind.2015.12.002

into account the information of proposed interface classification, but also represents the relationship between the interface and other entities of the product model. Finally, the interface compatibility rules play an important role to guarantee the right integration of the different components in one mechatronic system and to indicate the multidisciplinary collaboration with the support of interface model.

To summarise, the multidisciplinary interface model provides a common representation for the interfaces defined by design team members from several disciplines and expertises. Thus, on the one hand, the proposed model ensures the consistency of interface which may be defined by the different designers. On the other hand, it helps the designers guarantee the correct integration of different components and in a second perspective it may ensure the multidisciplinary integration and collaboration among design teams.

The paper is organised as follows. Section 2 presents a review of related work on interface classification, interface model and interface compatibility rules. Section 3 introduces the first part of the proposed multidisciplinary interface model for the design of mechatronic systems, i.e. interface classification. In Section 4 the interface model as an extension of product model by making use of the proposed interface classification is defined, and the interface compatibility rules with the support of interface model is then introduced. A process based on the multidisciplinary interface model which can be used during the design process of mechatronic systems is finally presented in this section. A case study of 3D measurement system will be introduced in Section 5 to implement the multidisciplinary interface model. Section 6 will provide a detailed discussion on the multidisciplinary interface model. Finally, the authors draw the conclusion and some further work in Section 7.

2. Related work

From the mid-80s, the interface between systems or sub-systems has been widely used in software engineering [9,10]. During development process of software, separated module of a program executes one aspect of the desire functionalities. Such modules interact with each other through interfaces. As system becomes increasingly complex, a complex system is then divided into sub-systems. The interface definition is at the heart of the multidisciplinary nature of Systems Engineering [11]. Interface management is considered as one of the most powerful tools of systems management [12]. The interface in mechatronic systems which refers to the logical or physical relationship integrating the elements of one mechatronic system or the elements with their environment can be used to describe the interactions of sub-systems designed by different disciplines [6]. Therefore it is significant to develop a proper interface classification in order to represent much more details of an interface and help designers to avoid the confusion by the misuse of interfaces.

To solve the collaboration problems during the design process of mechatronic systems, Steward [13] describes the interactions of sub-system as "information flows", but such information flows are not described in details. Counsell et al [14] describe the connections between different components as material, information and power. Sellgren [15] proposes that interfaces can be classified as attachment, constraint and contact. His proposition mainly focuses on the physical interface. An international standard ISO/IEC 81346 [16] also specifies how to define a physical interface. However, modelling and controlling relationship for the formalised specification of interfaces have not been fully realised [17]. Chen et al [18] classify the interfaces as the "constraints" between electrical/electronic discipline and mechanical discipline. But the interfaces between software discipline and electrical/electronic discipline or mechanical discipline have not been mentioned. Pahl et al [19] present a method named Modular Product Development (MPD) for complex system. This method starts by breaking down the product into modules. The exchanges of energy, materials, and signal between the modules are mentioned in this method. Liang and Paredis [6] develop a more detailed classification based on the proposition of Pahl et al by refining the energy as electrical, mechanical and hydraulic, etc. However, these two methods do not consider the interface between software and other disciplines. Komoto and Tomiyama [20] believe that some physical implementations have nothing to do with transformation of energy, material, and signal (e.g. a function to fix connection between two mechanical components or a function that holds a position). But these physical implementations can be used to connect two components as the interfaces. Thus geometric features play a crucial role during the design process. Authors point out that attention should be also paid to such geometric information. Sosa et al [21] distinguish the interfaces in terms of spatial dependency, structural dependency, energy dependency, material dependency and information dependency. Such classification method may lead to the misuse of overlapping interfaces. For instance, the material dependency is described as "a requirement related to transferring airflow, oil, fuel, or water". However, such process of material transfer often occurs with the energy transfer which was defined as "energy dependency". Bettig and Gershenson [7] underline the interface representation problem and try to identify an overall representational schema. Seven classes of interfaces are firstly suggested: Attachment interface, transfer interface, control and communication interface, power (electrical) interface, spatial interface, field interface and environmental interface. The seven interface classes are then reduced to four general classes of interface: attachment interfaces, control and power interfaces, transfer interfaces and field interfaces. The reduced classification defines the field interface as "an interface that transmits energy, material or signal as an unintended side-effect of the intended function of a module". This classification begins to consider the negative effects of interfaces. However, the field interface is so generic and need to be detailed.

By analysing the interface classifications for mechatronic systems, the authors show the limitations of each previous classification in Table 1:

As above mentioned, the interface classification gives much more details of an interface. Such details should be included in the interface model. The interface model has been represented by current product models. A non-exhaustive list of current product models is presented hereafter. Standard for the Exchange of Product model data (STEP) is actually a series of standards, known as ISO 10303 developed by experts worldwide [22]. The Parts known as APs (Application Protocol) of STEP define the scope, context and information requirements of applications. The interface model has partially developed in some specific disciplines. The development of STEP started in 1984 and its initial purpose is to represent and exchange the 3D objects in Computer-Aided Design (CAD) and related information [22]. In 1994, the first set of standards (i.e. the 1994 version of STEP) was released as a geometry-centred product model [23,24]. However, the geometry-centred product model is no longer suitable for the collaborative design because it includes only the boundary representation, the data such as design constraints, design parameter and design history which may be of great importance for heterogeneous CAD systems have not been involved [25]. Through the efforts of the STEP parametrics group, a series of standards for feature-based data exchange has been released in order to overcome the limitation of geometry-centred product model [26]. AP 203 Edition 2 is developed based on feature information for the configuration