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Survey on mechatronic engineering: A focus on design methods and product models

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ABSTRACT

According to the principles of concurrent engineering and integrated design, engineers intend to develop a mechatronic system with a high level integration (functional and physical integrations) based on a well-organised design method. As a result, two main categories of issues have been pointed out: the process-based problems and the design data-related problems. Several approaches to overcome these issues have been put forward. To solve process-based problems, a dynamic perspective is generally used to present how collaboration can be improved during the mechatronic design. For design data-related problems, solutions generally come from product models and how to structure and store the data thanks to the functionality of data and documents management of Product Lifecycle Management systems. To be able to assess design methods and product models, some criteria are proposed in the paper and used to evaluate their added value on integrated design of mechatronic system. After this assessment, main outcomes which focus on the combination of design method and product model for improving the design of mechatronic system are finally discussed.

1. Introduction

The term "Mechatronics" originated at the Yaskawa Corporation from the combination of mechanics and electronics, to describe the integration process of four disciplines: mechanics, electronics, computing and automatic control [1]. Because of the technology development, mechatronics becomes the synergistic integration of physical systems with information technology (IT) and complex decision-making in the design, manufacture and operation of industrial products and processes [2]. In this section, mechatronic system specificities will be introduced. Due to these specificities, issues linked to mechatronic systems design will be presented.

1.1. Mechatronics and integrated design

Products are becoming increasingly complex and integrating technologies from several fields, such as mechanical engineering, electronic/electrical engineering and software engineering. Mechanical systems developed since the 1980s have thus evolved from electro-mechanical systems with discrete electrical and mechanical parts to integrated electronic–mechanical systems with sensors, actuators, and digital micro-electronics. These integrated systems, composed of hardware and software modules, are generally called mechatronic systems [3,4].

Mechanical system has started to integrate electrical and control functions to become a real mechatronic system, and several evolution steps have been generally observed. Fig. 1 [5] presents this evolution, the different involved engineering disciplines and the overlaps between them. First, Actuators (A), represented on the right angle of the triangle, are added. They are in charge of managing actuation forces and speed. It can be regarded as the first combination of electronics and mechanics disciplines. To supply power to these actuators, external power is needed and generally provided by electrical engineering disciplines. Second, the Embedded control (E), comes "with the goal of an automatic or more reproducible process" [5]. On the top angle of the triangle, embedded control can be considered as the overlap between the electronic and software disciplines. Third, the Sensors (S), on the left angle, allow the system to get detailed information about the status of the system and to fulfil correctly to the various environmental conditions. It is considered as the overlap between the mechanics and IT disciplines. Finally, the Communication (C) is now considered as the central piece of the system, especially for distributed systems. It allows integrating the sub-system into the whole product/system.

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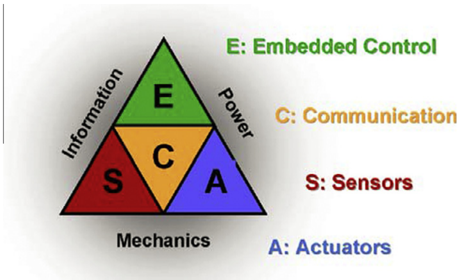

Fig. 1. Mechanical systems integrating electronics in interaction with information and power [5].

This kind of evolution allows fulfilling much more functions compared to a pure mechanical system or pure electronic system. "But all this could still be just called an automated system; mechatronics means more than this" [5]. Mechatronic systems are the resulting product of a global concurrent engineering or integrated design approaches [6,7]. To achieve such integrated design, Abramovici and Bellalouna describe the problems to overcome as "Process-based problems" and "Design data-related problems" [8].

According to Abramovici and Bellalouna, "Process-based problems" are linked to the coordination and the synchronisation of the "different disciplines, specific development processes, activities, tasks and results across all fields is not sufficiently supported", but also to the fact that complex "coherences and interactions between the disciplines are considered in a late development phase". Furthermore, "comprehensive integration, configuration, change and release management across all disciplines is little or barely supported" [9].

The second kind of difficulties encountered during design of mechatronic systems, called "Design data-related problems" [9], is related to the edition and management tools heterogeneity. For example, mechanical designers use Computer Aided x (CAx) applications to support the product development process. The data generated are generally stored in Mechanical Product Data management (M-PDM) systems while electrical and electronic designers use Electrical/Electronic Engineering Solutions (EESs) to create data which are stored in Electrical PDM (E-PDM). Software designers use development solutions to create source code that is managed thanks to Software Configuration Management (SCM) or Concurrent Versions System (CVS) systems. This heterogeneity in terms of product data, data models and data formats leads to several problems that can be summarised as no adequate multi-disciplinary integration of product data [10].

All these multi-disciplinary integration issues could have some negative impacts on the final integration of the mechatronic system. Fig. 2 presents several levels of integration for a mechatronic system. The first kind of integration is called "separated components". In this case, components are designed separately and are just incorporated in the same system thanks to cable. The second level of integration corresponds to the concept of "joined components". The mechanical component will be designed in order to place the electrical and/or the electronic components in juxtaposition with each other. Distances between components have been reduced. The third kind of integration is called "included": electronic components are spread out into the whole system, but this kind of integration does not achieve a "real" integration. Finally, the ultimate integration level is the "merged" components: electronics is integrated as close as possible to the mechanical and electrical components. Parts are gathered in a consistent and functional manner and mechanical parts can also be used as signal transmitter. The contributions of this integration are various:

- Physical integration: spatial and weight optimisations.
- Functional integration: detection, communication, control/information processing allow the system to provide new functionalities and to be reliable.

In this section, the design of mechatronic system, the issues related to multi-disciplinary integration and their possible effects on the final integration of mechatronic system have been discussed. The following section describes the focus of the paper and the way the survey will be organised.

1.2. Focus of the paper and survey organisation

To achieve the optimal integration for the final mechatronic system, several problems have to be overcome. As described in the previous section, these problems could be divided into two main categories, the "Process-based problems" and the "Design data-related problems". To overcome these problems, several efforts have been presented in different communities. The paper aims at presenting some of these approaches. In Section 2 the identified collaboration challenges are presented and discussed in detail. For a better understanding of the added value of every methods or models, several specific collaboration criteria based on these collaboration challenges are also exposed in this section. Section 3 gives a review on existing design methods used in mechatronic engineering. They are all considered as a potential solution to the "Process-based problem", focusing on the dynamic of the collaboration. Section 4 presents various product models enabling mechatronic design and disciplines integration, dedicated to "Design data-related problems". Section 5 introduces the assessment of studied design methods and product model according to the specific criteria derived from the collaboration challenges in Section 2. Section 6 proposes a synthesis and discussion on the main outcomes obtained. Last, the concluding section summarises the proposed survey and key ideas of the paper.

2. Collaboration challenges in design of mechatronic system

As depicted previously, an "integrated design" for mechatronic system embodies in two aspects: a design process with high-level multi-disciplinary collaboration and a mechatronic system with

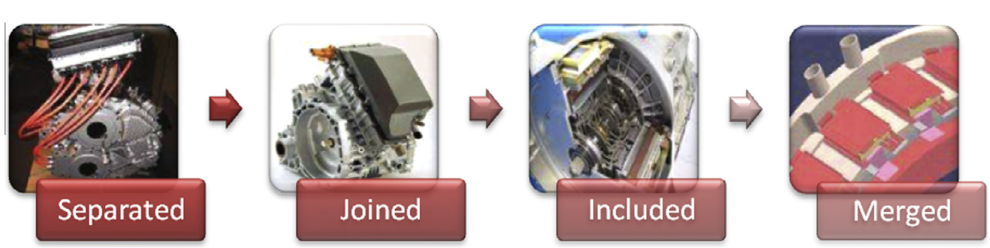

Fig. 2. The different integration levels in mechatronic systems [11].