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Design of an Electronic Throttle Body Based on a New Knowledge Sharing Engineering Methodology

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Abstract. To minimize the number of iterations and correction returns while designing a system, sharing crucial parameters and data between different actors is needed. Since mechatronic systems are considered complex because of their multi-disciplines, their design requires collaborative work to ensure the sharing of parameters between contributors from different domains. This paper proposes a new methodology based on the collaborative design to choose the architecture of a mechatronic system. This methodology is structured around three main phases: the pre-collaboration phase, the collaboration phase and the post-collaboration phase. The proposed methodology has been validated by applying it on a mechatronic system called Electronic Throttle Body (ETB). In order to share the different established activities and capitalize knowledge, KARREN (Knowledge Acquisition and reuse for Robust Engineering) a collaborative tool from DPS (Digital Product Simulation) a French company, is used in this project to help us to choose the appropriate architecture of the Electronic Throttle Body.

Keywords: Collaborative design · Mechatronic system · Methodology · ETB · KARREN

1 Introduction

Mechatronics is defined as a synergic integration of mechanical, electronics, information systems and computer systems in the design of a product in order to increase and optimize the functionality. This alliance requires a simple and fast data exchange between different disciplines to obtain a product of high quality, low price and a short time. For this reason, the concept of collaborative engineering has replaced sequential engineering to improve communication between project actors and to ensure robust and efficient sharing of knowledge. In this context, knowledge Based-Engineering (KBE) is a technology able to capture and reuse knowledge to reduce costs and time of development. This technology has large application such as knowledge reuse and

collaboration support [12]. In this direction, this paper proposes a new methodology based on a collaborative design to choose the most appropriate architecture of a mechatronic system using KBE application to support collaboration between actors.

The paper is organized in several sections. Section 2 presents a review of related works. In Sect. 3, our methodology is presented in details. In Sect. 4, the proposed methodology is illustrated on a case study. Section 5 gives some results and Sect. 6 summarizes and concludes the paper.

2 State of the Art

2.1 Mechatronic Systems Development Methodologies

As previously mentioned, mechatronic systems are known with their multidisciplinary nature, which increases the complexity of the design. In order to decrease this complexity, various groups of researchers to develop mechatronic systems with high quality and low cost have done significant works. Four types of development methodologies are discussed in this section.

First, the methodologies based on the optimization with integration of control were presented as methodologies to develop mechatronic systems. In this context, Zhang et al. [21] proposed an integrated approach for mechatronic design to facilitate the control system. To improve this work [10] developed a design framework called Control For Design (DFC). This approach emphasizes the importance of designing the control parameters simultaneously with the structural parameters even though it is possible to change the controller parameters after the system is built. Another methodology has been proposed by Villarreal-Cervantes et al. [20] to formulate the mechatronic design problem of the 5R 2Dof parallel robot and its Proportional-Integral-Derivative (PID) controller. They integrated a nonlinear dynamic optimization problem. This work concerns parallel planar robots. Nevertheless, some applications require high performance positioning systems with a spatial parallel mechanism. In this framework, the contribution of Lara-Molina et al. [9] takes into account the structure and control design variables simultaneously. They proposed an optimal design methodology for Stewart-Gough robot. This robot is a three-dimensional mechanism where its movable platform is connected to the fixed base by six legs. This methodology aims at maximizing the accuracy of positioning to optimize the overall performance of the robot. In these previous works, effective approaches have been introduced. However, the improvement of the system performance based on the possibility of modifying controller parameters was overlooked, which represents an important criteria in design evaluation.

Methodologies based on the design evaluation are another type, which aims at developing mechatronic systems. Moulianitis et al. [16] proposed an evaluation index that includes the complexity, flexibility and intelligence of mechatronic systems. In addition, Hammadi et al. [8] proposed a multi-criteria performance indicator called Mechatronic Design Indicator (MDI) as a neuronal network of radial basis function. This indicator provides accurate information for decision making while decreasing design time. However, this methodology overlooks other mechatronic design

requirements such as risk assessment, cost, etc. As an improvement to this work, Mohebbi et al. [15] developed a new multi-criteria profile. This profile includes five criteria, which are cost, flexibility, complexity, intelligence and reliability of mechatronic systems. These criteria can be determined using a specific mathematical function. This methodology is applied to the conceptual design of a 6-Dof robotic manipulator. Following this work, Moulianitis et al. [17] proposed a new index includes seven criteria, which are configurability, adaptability, dependability, decisional autonomy, motion ability, perception ability and interaction ability. In formulating this index, the cost and the complexity are taken into account. The proposed index is applied to the design of firefighting robot in order to evaluate its design solutions. However, all these approaches are not extended for use in the detailed design phase.

Due to their flexibility in design representation, bond graphs and evolutionary algorithms are considered as an efficient method for system representation in detailed phases as well as preliminary phases. Seo et al. [19] developed a unified and automated methodology for the design of mechatronic systems. The proposed approach consists in combining Bond-Graphs (BG) and Genetic programming (GP). However, this work is oriented to the structural part in mechatronic systems and lacks the controller part that is always present in these systems. In order to achieve the best topology and parameters of a mechatronic system, Behbahani and De Silvia [5] proposed a new evolutionary algorithm. This algorithm makes it possible to explore efficiently the design space. In this work, the control part has been taken into account. Another methodology combining (BG) and (GP) is presented by Samarakoon et al. [18]. This approach was implemented in an industrial fish cutting machine. Nevertheless, the nonlinearity of the machine has been overlooked in this work.

Finally, although the structure of mechatronic systems has been treated during these previous works, the control part has been overlooked in some of them. This absence can influence the reality of these systems since the control is an essential part in mechatronic products. In this context, several works to model mechatronic systems have been done using the object-oriented modeling language Modelica and Dymola software. This tool makes it possible to control mechatronic systems while modeling their structures in the same environment. Modelica has been used by Ferretti et al. [7] to model and simulate the behavior of a mechatronic machining center. Another work was done by Mcharek et al. [13]. In this work, a mechatronic system called Electronic Throttle Body (ETB) was modelled with Modelica language. The contribution of this work is represented by taking into account the integration of the fail-safe technique in the ETB model.

2.2 Methodologies Based on Collaborative Design and Knowledge Sharing

Over many decades, the complexity of products is in increase. This increase implies also an increase in the number of people needed to develop these systems. Actors need to interact and exchange crucial data to obtain an ideal product. This can be achieved by following collaborative design. Such a strategy enable companies to reduce costs, improve quality and reduce time to market while innovating their products. In this context, researchers developed several methodologies in order to exchange and share

knowledge. First, methodologies based on Product Lifecycle Management (PLM) have been used to exchange knowledge between actors. Chen et al. [6] developed an approach of dividing the mechatronic system into components and classifying them into two parts an electrical and a mechanical one. After this classification, the constraints between components are defined and a table summarizing the components and the connection between them is established. This methodology reduces the complexity of mechatronic systems but the classification of components can cause problems while developing these systems. Alexopoulos et al. [2] proposed a methodology for integrating data mechatronic system into the PLM system. In this approach, Automation Markup Language (AutomationML) has been used as an intermediate format to exchange data between different tasks. This language facilitates the integration and exchange of data. However, there are not many translation tools available because AutomationML is a new format. Another interesting study is proposed by Abid et al. [1] based on the use of behavioral and structural diagrams of system Modeling Language (SysML) to model structure of a complex product in a PLM system. The PLM in this case makes it possible to coordinate the exchange between designers. This methodology is validated with a 3D robot. All these methodologies have shown their efficiency in the exchange of data between actors. However, they do not allow an easy access to data embedded in different models. Second, in the field of simulation and modeling, the goal is to provide an integrated environment for engineers in order to achieve optimal multi-domain design. This can be satisfied using technology called Process Integration and Design Optimization (PIDO). There are several tools to apply this technology such as Model Center [14] and Isight. In this context, Azzouzi et al. [3] proposed a methodology aims at improving system modeling by applying PIDO technology. This approach has been validated by applying it to a hybrid vehicle using an optimization tool (Model Center). This tool is used to identify unknown parameters of a system. An improvement of this methodology can be made by minimizing the error between model results and experimental data. However, PIDO technology is used in the optimization of a single architecture not to share knowledges in order to choose the most appropriate architecture among several ones of a system. Finally, Knowledge Based-Engineering (KBE) tools are used in collaborative design since they allow knowledge capitalization and reuse. Several methodologies were done using KBE tools. Badin [4], during his PhD research work, developed a new methodology based on configuration management of crucial knowledge for product design and numerical simulation. This approach allows engineers to capitalize, reuse and maintain coherently knowledges between different domains. As an improvement of this methodology, decision support approaches to guide designers can be integrated. Mcharek et al. [12], also proposed a new methodology based on KBE concept. This approach is characterized by its ability to support designers during design phases as well as its ability to reuse design results. The contribution of Mcharek et al. [12] is illustrated by its application to the design of a mechatronic system called Electronic Throttle Body (ETB). We will consider the same system during the application of the methodology. Therefore, our contribution in this paper is illustrated by the development of a new methodology, which will help us not only to collaborate between different actors of one architecture of a mechatronic system but also to compare between several architectures and to choose the most appropriate one.

3 Proposed Methodology

The interaction between several companies working at the same time for the same project has become a standard for manufacturers and more practically in the aeronautical and automotive fields. These fields are known by their complexity because of the integration of different disciplines. Therefore, each actor must have access to the right information, at the right time and with the right information format. Mechatronic systems are one of complex systems, which are characterized by the combination of mechanical, computer systems and electronics aided by control strategies. These systems can be represented by various architectures or solutions, which make their design very tedious. The design process is composed of seven steps as shown in Fig. 1. In this context, our contribution aims at developing a new methodology that helps engineers to choose the best architecture of mechatronic system among several ones in the conceptual phase. This methodology is divided into three main phases. The first phase of our methodology starts with an idea of designing a system in order to satisfy one or more specific needs. Once the function of the system is defined, a search of different design solutions must be established. If the different solutions have been selected, we can create the models for each solution. These models have different forms such as 3D, fluid, procurement and dynamic models. During the second phase, all project actors will collaborate with each other. This phase represents the core of our methodology since at this stage the actors can share their work to detect the inconsistencies between them and reduce correction returns. This phase starts with the extraction of crucial data from different established models and from the requirements imposed on the system. Once important data are extracted, they can be shared in the collaboration support. Indeed, only the data characterizing the interdependence between disciplines need to be shared. The last step of the second phase consists in visualizing and managing conflicts either in one model or between several models. In the third phase, a comparison between the different solutions or architectures of the system must be done and the best solution can be chosen based on this comparison. Figure 2 illustrates the global process of our methodology.

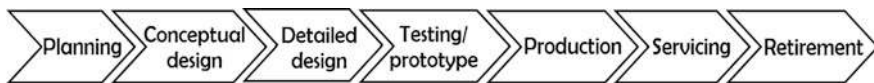


Fig. 1 Product development process [11]

4 Case Study

The proposed approach is used for the choice of the best architecture among three of an electronic Throttle Body (ETB). The ETB adjusts the airflow entering to the combustion engine. Following the methodology steps, we apply it to the ETB. This application starts with finding the different solutions.

For the ETB we choose three different architectures one with a DC motor, one with a brushless motor and another one with a stepper motor. After choosing these

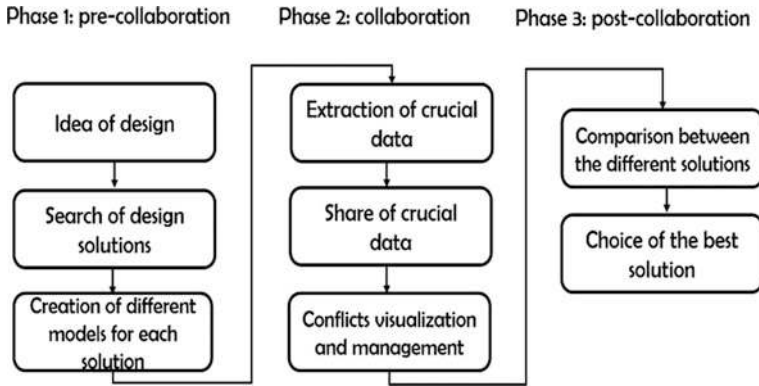


Fig. 2 The global process of the proposed methodology

architectures, the different models for each architecture must be established. For this application, three models will collaborate with each other: a dynamic model using the environment Dymola and the object-oriented language Modelica, a 3D model using CATIA and procurement model, which consists in finding the most appropriate motors conforming within simulation results. The ETB model with a DC motor in Dymola environment is illustrated in Fig. 3. The DC motor is replaced by the brushless motor in the second alternative and by the stepper motor in the third one. After creating these dynamic models with Dymola software, the performances of each motor such as torque, power, voltage, etc. must be visualized. In the procurement models, three motors have to be chosen conforming within visualized performances. Indeed, a single 3D model must be created since the difference between the three alternatives concerns motors type not the geometry.

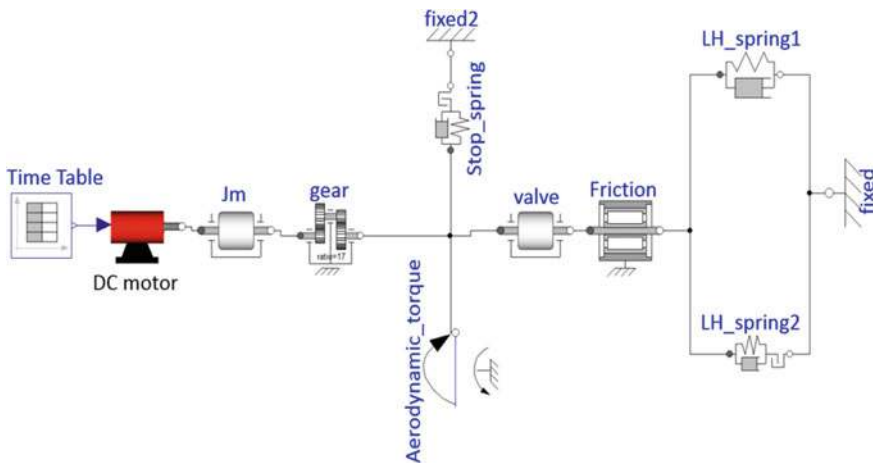


Fig. 3 ETB model with a DC motor in Dymola environment

Once all models have been created, crucial data can be extracted and shared between actors. Sharing data consists in organizing it in Information Core Entities (ICEs), which are generic entities aims to organize and capitalize crucial data, as presented in Table 1. In the end of this application, the existing conflicts are visualized and managed and the best architecture is chosen.

Table 1 Organization of crucial data

Parameters	Unit	Description	Constraints
ICE_performance motor			
P	W	Power of motor	–
C	N.m	Torque of motor	<1.5 N.m
ICE_dimension motor			
L	mm	Motor length	–
D	mm	Motor diameter	–

5 Results and Discussion

Our methodology was tested in KARREN platform. Figure 4 summarizes the obtained results. Only the chosen DC motor in procurement model can be implemented in the 3D model. The other chosen motors have incompatible dimensions with the 3D model. Therefore, we choose the first alternative of the ETB with a DC motor.

Instance	Quantity	Value	Model geo	Model multi-phy1.1	Procurement1.2
ICE_dimmoteur.1					
longueur	Length	mm	75.9mm		44.7mm
Diamètre	Length	mm	35.39mm		26mm
ICE_perfomoteur.1					
Puissance	Power	W		5.3W	4.5W
Couple	Moment	N.m		0.045N.m	0.0158N.m

Fig. 4 Obtained results in KARREN platform

6 Conclusions

This paper has presented a new methodology based on collaborative design and knowledge sharing to choose the best architecture among several ones of a mechatronic system. This methodology was applied to an Electronic Throttle Body. In this application, we considered three alternatives each one with a different type of motors (with a DC motor, brushless motor and stepper motor) and we created three models for each alternative which are 3D model, procurement model and dynamic model.

In our future work, we will add another domain such as safety system to improve our methodology.

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