Computers in Industry 94 (2018) 26–40

Contents lists available at ScienceDirect

Computers in Industry

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

An ontology for numerical design of experiments processes

Gaëtan Blondet, Julien Le Duigou*, Nassim Boudaoud, Benoît Eynard

Sorbonne Universités, Université de Technologie de Compiègne, Mechanical laboratory Roberval UMR UTC/CNRS 7337, France

ARTICLE INFO

Article history:
Received 22 February 2017
Received in revised form 10 September 2017
Accepted 19 September 2017
Available online xxx

Keywords:
Ontology
Design of experiments
Simulation data management

ABSTRACT

Numerical Designs of Experiments (NDoE) are used in a product development process to optimize the product. A NDoE may combine a costly numerical model and numerous experiments. The NDoE process consequently becomes very expensive. However, some methods and algorithms were developed to shorten the NDoE process, as sensitivity analysis, surrogate modelling and adaptive DoE. Because of their complexity, advanced expert knowledge or a long preparation step is required to optimally choose and configure all of these methods, in order to run the most efficient NDoE process.

To answer this issue, a knowledge management approach is proposed in this paper. It capitalizes and reuses knowledge about NDoE process. This solution is proposed because of the lack in term of models and standardized processes for this specific NDoE application. An ontology was developed to manage, share and reuse knowledge and enable queries for information retrieval in a database. The database lists every NDoE processes executed. Then, the knowledge is analysed by a decision-support system to help designers to choose the best configuration.

1. Introduction

Numerical simulations are used in a Product Development Process (PDP) to continuously optimize products to improve quality to reduce the cost and the time to market. Simulation activities lead to fulfil customer's requirements without any physical prototype and with a minimal amount of re-design loops. Numerical simulations are more and more numerous and complex, as decision processes are more and more based on numerical models. A simulation data management strategy must be set to control the simulation process and to make it as profitable as possible [1,2]. These simulations may need and produce a large amount of data. Numerical models may cover multiple physics on multiple parts of the product. Simulation data must be shared across extended enterprises to enhance collaborative engineering activities between different teams.

A Numerical Design of Experiments (NDoE) process is defined by an ordered sequence of simulations, based on a parameterized numerical model. Each simulation/experiment is defined by a specific set of values of model's parameters. NDoE can be used to model uncertainties or to optimize the product. NDoE multiply the simulation process cost and the amount of data by the number of experiments. NDoE processes may increase drastically the need to manage data and to shorten the simulation process.

The aim of NDoE process is to consider the properties, the environment and requirements of the product as variables. NDoE process fulfils specific objectives, such as design optimization [3], surrogate modelling [4] or sensitivity analysis [5]. For each objective, specific methods post-process outputs of each experiment. Some of these methods can shorten the NDoE process, by minimizing the number of required experiments, as:

- sensitivity analysis methods identify most influential parameters of the numerical model, according to the studied output. This dimensionality reduction decreases the number of required experiments.
- surrogate modelling methods replace the initial numerical model by a cheaper function (e.g. polynomial functions). Once a first NDoE is executed with the initial numerical model, a surrogate model is computed and can be used for further studies. This method reduces the computational cost of future experiments.
- Adaptive sampling methods [6] are applied to obtain an optimal NDoE. An optimization algorithm, as gradient-based algorithms and metaheuristics, can be used so that each experiment gives more relevant results. Thus, the number of required experiments can be minimized.

* Corresponding author.
E-mail addresses: gblondet@utc.fr (G. Blondet), Julien.Le-Duigou@utc.fr (J.L. Duigou), nassim.boudaoud@utc.fr (N. Boudaoud), benoit.eynard@utc.fr (B. Eynard).

http://dx.doi.org/10.1016/j.compind.2017.09.005

While these methods shorten the execution step, they require advanced knowledge to be configured, especially if they are combined and applied to complex products. For instance, an adaptive NDoE may be used for surrogate modelling with a multi-physic simulation model with 50 parameters, which takes one day to be executed. Designers must choose wisely the type of initial NDoE, the number of initial experiments, the metaheuristics to search new useful experiments, the type of surrogate model, the criterion to select the best new experiments, etc. A wrong configuration may lead to a significant waste of time and computational resources. The configuration of the NDoE process is as critical and difficult as the product is complex and simulations are expensive. The time and the knowledge required to define the NDoE process is increased. As discussed in [7], a solution consists in efficiently managing data used in each NDoE process. Regarding a SDM strategy, data are capitalised and reused to shorten the configuration step of the simulation process.

This work was done in the French FUI 16 project SDM4DOE ("Simulation Data Management for Design of Experiments"). This project aims to propose an open-source framework to define, run and manage NDoE processes during the PDP. A SDM tool supports NDoE processes to capitalize, trace and reuse data, in order to help designers for further studies. First applications of this framework are being done in automotive industries (Valeo[1]) and for civil engineering applications (NECS[2]).

In this paper, an ontological approach is proposed to structure, share and reuse knowledge required to set complex and efficient NDoE processes fast. The paper is structured as follow: Section 2 presents a literature review of product development ontologies. Section 3 describes the proposal: a specific ontology for the NDoE process. This proposal is illustrated by a use-case, in Section 4, with a specific application in mechanical design, extracted from the project SDM4DOE. A discussion on the use of this proposed ontology in enterprises, to manage and reuse data and knowledge linked to NDOE processes, concludes this paper.

2. Ontologies in product development process

An ontology can be defined as an "explicit specification of a conceptualization" [8,9]. In other words, ontologies describe, by a shared vocabulary:

- semantic representations of concepts of a specific domain.
- relationships between these concepts.

An ontology must be easily understandable and editable [10]. It should support links with other ontologies to enrich and extend the semantic domain. Many ontologies support a PDP subjected to collaborative constraints, heterogeneity, interoperability, temporal changes and knowledge management issues in every step of the product lifecycle.

Since NDoE process may involve specific concepts used by different teams and departments, a specific ontology is appropriate to give a clear and sharable semantic description of this domain.

The literature review shown in this section covers (1) ontologies proposed to support the PDP and (2) ontologies which support more specific concepts involved in the NDoE process. The aim of this literature review is to identify already described concepts and missing concepts.

[1] http://www.valeo.com/en/who-we-are/

[2] http://necs.fr/

2.1. Literature review on product ontologies

Many applications of ontologies have been developed to support the PDP. Their common goal is to improve system interoperability and collaborative processes. They cover different stages of the product lifecycle, with different level of details. All of these developments are analysed to identify concepts, involved in the semantic domain of NDoE processes, which are already described or not. This study will provide elements to define a specific ontology for NDoE processes, enriched by existing developments. The semantic domain of NDoE process, covers, for instance, methods for surrogate modelling [11], methods for sensitivity analysis [12], types of NDoE [13], the concept of experiment, optimization algorithms. This semantic domain is also connected to other concepts such as numerical model, CAD model and product data.

The ontology PRONOIA2 manage product data from the design and manufacturing process, focusing on the Beginning of Life (BOL) of the product lifecycle [14]. This ontology is composed of three main levels of description, from the most general description (Meta-ontology) to a specific description (application ontology). PRONOIA2 adds a description of product evolutions through the BOL. Evolutions are represented by spatiotemporal concepts, as transformations (ex: welding, riveting, clinching, etc.), changes (ex: addition, deletion, permutation, etc.) or movements. These concepts are linked to the physical description of the product, which describes geometry and assemblies. It seems unable to manage data from the numerical simulation process, according to the current description. But the *meta*-ontology is general so that new specialized sub-classes could be added. For instance, a new subclass of the class "spatial_region" could be added, describing the numerical description of the product, in the same way as the class "Physical-product".

An ontology was proposed to enrich exchanges of product data, commonly covered by standards, such as STEP [15]. This development focused on the management of geometric data, as variational geometric constraint data. The variational aspect is described as a variation of spatial parameters, linking a referenced feature and a constrained feature in the CAD model. Such a semantic description can be linked to the semantic domain of NDoE process by concepts as parameter and geometric model.

PROMISE Semantic Object Model [16] was translated in OWL (Web Ontology Language) and improved to create an ontology. This ontological model supports the concepts used for product design, and for various processes and industrial sectors. The translation was made to enrich the data model to be used for closed-loop Product Lifecycle Management. The classes "physical_product" and "As_designed_product" embed product identification data and definition data, as CAD model, tests and specifications. These concepts are used in the semantic domain of the NDoE process.

ONTO-PDM is a product ontology managing heterogeneous data, as material used and related properties, relationships between components and products, versions, manufacturing equipment, etc. [17]. Two standards, ISO 10303 and IEC 62264, were used to develop this ontology. ISO 10303 gives a sharable description of product information (geometry, identification data, etc.). IEC 62264 links the ontology with the Manufacturing Execution System (MES) and the Enterprise Resource Planning (ERP). It seems that Onto-PDM does not cover any analysis activity, such as numerical simulation, but it is still based on ISO 10303, which specify data models for numerical simulation model.

Some ontologies have been developed for the manufacturing context. For instance, OntoSTEP-NC [18] was proposed to improve interoperability between CAD, CAM and MOCN tools. OntoSTEP-NC is based on the STEP-NC standard, which is built on ISO10303-AP238 and on ISO10649. These two standards can manage