Ontological Approach to Structuring of Industrial Products

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Abstract: The use of ontologies in engineering knowledge representation has been accelerated in recent years by the need to integrate them in collaborative development platforms. New product development requires the creation and evaluation of product development strategy, the organization and product concept generation, designing, testing and validation of product design, its manufacture, marketing and ensuring the product warranty and post-warranty service. Due to the existence of mechanisms for describing the concepts and their characteristics, ontologies offer many of the features that can support a science from a descriptive viewpoint and beyond. The work presented here aims at designing a generic ontological model of the product structuring models’ domain, suitable to be easily extended to cover the many sub-domains of product development, thus facilitating the design of such application ontologies in the future, and their implementation in CAx platforms and data management systems. As a first step, the article presents the problem as a whole, followed by a brief presentation of ontological engineering concepts, and finally it presents an ontology case study for modeling wastewater centrifugal decanting equipment.

Keywords: New Product Development, Knowledge Representation, Ontologies, Centrifuge Decanter

1INTRODUCTION

Engineering, with all its components, is in constant change due to the fundamental and applied research results in all related fields. In particular, production systems are affected by the need to achieve both quality and cheap products in the shortest time without polluting the environment. Any product resulting from engineering work has its own life cycle. Specific literature examines a product from three points of view: a technical, an economic and a social one. The product must meet, if possible, multiple criteria such as: it must always correspond to customer requirements; it must be operational for the entire period of standard use; and its exchange value should be competitive to similar products on the market. Product development requires certain activities which are based on reasoning, logic, structure, etc. and which is using large quantities of knowledge. New product development requires the creation and evaluation of product development strategy, the organization and product concept generation, designing, testing and validation of product design, its manufacture, marketing and ensuring the product warranty and post-warranty service.

All these activities require the use of tools and specific work methods. Developing the concept of integrated engineering, of product development methods, of design principles, of product life cycle has led to the emergence and continuous development of specialized systems for each stage of development. As a consequence, the first issues arose. It was mainly about the compatibility and interoperability of these systems. These inconsistencies caused by a fierce competition in the market of manufacturers of such systems were identified too late, and finding the solutions to the problems mentioned has also been delayed. Not exploring solutions at the right time had as consequence the increasing of problems to be solved. This problem, considered from the product designers’ perspective reveals the lack of solutions in information and models management. The multitude and variety of technical solutions that can be considered requires the use of integrated systems, including assistance in decision making, so that designers make sure their decisions are consistent with the needs of the future structural and functional product. Very many of the defaults that occur in the operation of a product are due to deficient preliminary analysis, completeness or inconsistency of information. In such a scenario, the accuracy and consistency of the final model is a key issue. The risk of developing a model affected by inconsistency is very large and can generate increased costs if the incompatibilities are discovered too late. Additionally, collaborative product development requires the establishment of clear criteria for compatible models results, especially if they are provided by geographically dispersed project teams. According to Tudorache, 2006, an efficient collaborative approach of the development process must consider the following three aspects: (1) the diversity of representation of information; (2) the integration of different models in the phase of conceptual analysis; (3) the validation of the overall solution consistency, the management and the propagation back on track of changes.

A possible solution to the invoked problems would be the use of integrated PLM systems (Product Lifecycle Management). The advantages of PLM systems are many, even with the absence of compatibility and interoperability with other systems of this entity. Recent studies about the future of PLM systems and the developments occurring in IT, particularly those related to the Semantic Web, converge to the next concept as a solution for the existing problems: ontologies. Today, they are considered the key to the success of information exchange and semantic interoperability between people and machines / equipment, in complex environments. However the issue is not fully resolved and here we refer to the small and medium enterprises whose business is the development of either custom-made, small series or unique equipment. For this type of companies must create new
skills, like those presented by Lobonțiu&Lobonțiu (2010).

Developing ontology is not an end in itself. The effort to achieve ontology will be rewarded in the end by the results it generates. The benefits of using ontology in engineering modeling activities can be summarized as:

Sharing knowledge in the field. One of the main benefits brought by the use of ontology is the knowledge sharing among people and the software tools they use.

Sharing terminology. A consequence of sharing knowledge through ontologies among applications is that terminologies will be both shared and described in ontologies.

The explanation of specific knowledge and reasoning with them. An important benefit of knowledge explicitation is their exposure as formal representations facilitating the use algorithms.

Besides, these market actors do not have the financial resources to purchase PLM systems. The solution for them would seem to be the development of IT tools also based on the use of ontologies in order to maintain compatibility with the major players’ systems in the IT industry. Ontological Engineering that has started two decades ago captures lately the attention of many research groups, primarily due to the ease of knowledge modeling in any field.

2 ABOUT ONTOLOGY ENGINEERING

A widely accepted definition of ontology is given by Gruber (1993), namely: “ontology is a formal specification of a conceptualization”. Gruber (1993) argues that conceptualization is an abstract notion, a simplified view of the world that we want to represent, with a certain purpose. Regardless of the type of community that will change and share knowledge through ontology, human actors or agents (in artificial intelligence), ontologies establish a common terminology, and therefore conceptualization requires adequate formalization. As defined by Gruber (1993) conceptualization refers to objects, concepts and other entities that are assumed to exist in a particular area of interest and the relationships that keep them together. Whatever the domain, ontology consists of several elements, the most important being: concepts, relationships, attributes, instances and axioms. In other words, a conceptualization is an abstract, simplified view of the world that we want to represent with a particular purpose. Formal specification involves a vocabulary of representation in which the objects of the domain and the relations among them can be formally represented.

Borst (1997), after investigating the possibility of reusing the results of ontological engineering, has expanded Gruber’s definition outlining that to be useful, an ontology should be reused and shared between different applications; thus he proposed the following definition of “ontology as a formal specification of a conceptualization to be shared”. A year later, Studer et al. (1998) extended this definition by introducing a new criterion to ontology utility. Thus, ontology in order to be reused should make explicit assumptions of things.

The definition of ontology is in this case “a formal and explicit specification of a shared conceptualization”.

Several approaches to developing ontologies for products and services are known in several areas: biology (Lewis, 2004; Myhre et al., 2006, GOCD, 2013), medicine (Bickmore, Schulman and Sidner, 2011; Matthew, 2008), design (Contreras and Pintescu, 2013) and geosciences (Jung, Sun and Yuan, 2013; Hu, Tang and Lu, 2014). Regarding special products like machines or industrial equipment, problems were treated relatively briefly in Panetto, Dassisti and Tursi, 2012; Barb et al. and Tudorache, 2006 initialized the approach of a driving set.

In the specific literature and in the very diverse approaches to problem solving through or by means of ontologies one may find as many attempts to define the term ontology.

To clarify the concept of ontology Mizoguchi (2003) presents some distinctive elements of this concept as follows:

a) An ontology is more than a simple list of words, and this is because ontology provides a common vocabulary of terms specific to a particular area and which can distinguish between different concepts by the presence of a structure within the created ontological model, as an “is-a”-type formula.

b) Ontology is more than a hierarchy of concepts. A simple reduction of the construction of an ontology as a structured tree would not be sufficient to describe the complex relationships that we encounter in practice (e.g. a gearbox output shaft can be treated as part of the module or connecting element of the gear by means of a coupling with a piece of the serviced equipment).

c) Ontology is not only knowledge representation formalism. Through the diversity of relationships that may be associated to concepts within an ontological model, and the multitude of attributes that one can associate to them ontology becomes progressively a knowledge base with its own rules.

2.1 Ontology Classification

In Aubry, 2007, they present a classification of ontologies by different criteria, such as:

a) Classification according to the model that is intended to be designed:
   - the ontology of knowledge representation used in the design of ontological models for structuring information and knowledge;
   - superior ontologies (also called high-level ontologies), which contribute to modeling general concepts, being used by philosophers;
   - generic ontologies containing general concepts, but they are more abstract than the superior ones and they can be used in various fields;
   - ontologies for completing operations; they can be used for modeling tasks, activities, being useful to describe the activities within a task dedicated to solving problems;
   - domain ontologies; they are reusable within a domain and are modeling the terms and
There is no exact way or method to describe the development mechanisms of the ontology useful in the product development management. The specific literature presents general methods of achieving ontology, offered more as guidelines for a possible process of development (Grüninger and Fox, 1995; Fernandez Gomez-Perez and Juristo, 1997). Instead, practical approaches to ontology development must be within the limits of the available software tools. The practical activities of developing ontology overlap the general approach of ontology development, according to the following steps:

**Step 1:** Determining the scope and purpose of the ontology by asking a few questions to help the start and the clarification of the steps to follow:
- What is the domain covered by the ontology?
- What is the use of ontology?
- To what types of questions should ontology provide answers?
- Who will use and preserve the ontology?

It is possible that while creating ontology, the answer to these questions may change, but at some point, with their help, the objective of achieving an ontology model may be defined.

**Step 2:** The analysis of using existing ontologies. Reusing existing ontologies can be considered a requirement if our system must interact with other applications already using private ontologies or controlled vocabularies.

**Step 3:** Listing the essential terms in the ontology. They create a list of all the terms that are used either to be better understood, or to be explained.

**Step 4:** Defining classes and class hierarchy. There are several possible ways of developing a class hierarchy (Uschold and Gruninger, 1996):
- The bottom-up development starts with defining the specific classes and grouping these classes into more general concepts.
- The combined development is a combination of the two above. They first define the main concepts and then generalize them. They start with some high-level concepts and some specific concepts. Then they define the super class for this intermediate level.

None of these three methods is better than the other. The combination of these is easier for many developers of ontologies.

**Step 5:** Defining the properties of classes. The classes alone will not provide sufficient information to answer the questions in Step 1. One also needs to know their properties. For each property in the list, one must determine the class it describes. These properties become slots attached to classes. A slot is to be attached to the general class that has such specific property.

**Step 6:** Creating instances. The last step is creating the individual instances of classes in the hierarchy. Defining an individual instance of a class requires:
- choice of class
- creating a single instance of the class
- completing the values of slots.

Once this process is completed, ontologies need to be preserved and continually improved. All this work focuses on the use of methods to improve the ontology.

### 2.3 Ontology Development Tools

Since the inception of using ontologies and the increasing interest in knowledge representation a large family of tools has appeared, designed for activities such as creating, operating, updating and maintenance of ontologies. An important role in this process was played and still is by research laboratories in universities, among them Stanford University (Protégé, Ontolingua) and Cornell University (Vitro) are to be remarked.

Currently, a variety of software tools is available, used for creating the largest part of activities within ontology development. Completing a project often involves the use of numerous solutions such as editing or viewing of ontologies from external sources. Sometimes it is required the use of existing ontologies, and for this reason it is important that the ontology editing tools enable data interoperability, or the import or export of information to/from different formats.

One of the most popular ontology development environments is Protégé. Developed in the research laboratories of Stanford University, it was supported by the academic community both during its first test versions and then as an essential tool in the current creation and maintenance of ontologies. At present, Protégé has implemented a rich set of modeling knowledge structures and actions that support the creation, visualization and manipulation of ontologies in various representation formats.
2.4 Knowledge Representation in Protégé

At present, Protégé implements a rich set of knowledge modeling structures and actions that support the creation, visualization and manipulation of ontologies in various representation formats. Protégé can be customized to allow a support field for creating knowledge models and for entering data.

Protégé, besides being a powerful editor of ontologies in various representation formats, makes available its knowledge representation system based on frames. The framework in this model is the main block, the elementary entity representing the knowledge within a domain. Noy et al. (2001) present the Protégé knowledge representation model as constructed using classes, slots, facets and instances. This time the Protégé approach is made in the context of equipment or machinery type of product development management.

Classes and instances. A class contains a lot of entities. Entities are termed the instances of a class. Classes are organized into taxonomic hierarchies formed on the basis of the subclass relationship type. For example, the ElectricEngine class is a subclass of the more general class, the Engine. According to this semantic relation of such knowledge representation model, all entities in the ElectricEngine class are instances of the Engine class. However, a class may have multiple super classes, for instance, the ElectricEngine class at the same time can be a subclass of another class, namely the ElectricDevice.

Slots. They represent the properties of entities within a class. For example, the slot power can describe the power rated of the engine. In Protégé, these properties are first-order entities, meaning that they may be independent of the membership in a particular class. When such a slot is attached to a super class, it is inherited by all hierarchically subordinated sub-classes, and when an instance is created, all the slots attached to their class template become slots specific to an instance and may absorb the specific values of such instance.

Facets. They describe the properties of slots and are used to define the limits of the values allowed to slots. Examples of facets may be: the cardinality of a slot (which specifies how many possible values can take a certain slot), the range of values of a slot (specific to the valid values type of a slot), the maximum or minimum value for a numeric slot, etc.

The Meta-classes. These are classes whose instances are themselves classes. A meta-class is a template for building classes, in the same way that classes are templates for making instances. So, classes are the instances of meta-classes. A particular case of the use of Meta-classes is to offer the possibility of defining synonyms for class names (Motor or Engine).

Constraints, Axioms and Rules. The knowledge representation model of Protégé supports some limitations mainly related to specifying the complex constraints that simultaneously cover values of multiple slots or specify the transitivity of relations. Because the primary role of Protégé is the development, maintenance and management of ontology, the use of cumulated knowledge requires the involvement of other specialized tools, among which one may outline the applications of graphics and visualization, query, reasoning and data inference. Among them, an important role is played by Jess-the engine of rules (Friedman-Hill, 2002) as a tool of query and inferential knowledge in the ontology.

2.5 About Jess Rule Engine

Jess (Friedman-Hill, 2002), is a rules-based engine that enables the development of applications using the principles of rule-based programming, suitable for expert systems automation. Due to this feature it is often referred to as “expert system console” (expert system shell). In recent years, they have developed systems based on intelligent agents, which have a similar capability.

In Jess, as in CLIPS, there are three ways of representing knowledge: the rule, the functions and the object-oriented programming. The software in Jess can use either exclusively rules, objects, or a combination thereof. The inference engine is the one to decide which rules will be enforced and when, as the user is able to determine for each rule a priority or even a moment when to begin the execution of that specific rule.

3 CENTRIFUGE DECANTER MODEL

3.1 About Centrifuge Decanter

The centrifuge decanter is a device with a high speed rotation in which the mixtures are separated into different density components. This is relevant in most industrial operations where the solid, liquid and gas are combined in a single mixture, and their separation is required. The areas of application of decanter centrifuges can be food industry, petrochemical industry and industrial and domestic wastewater industry.

Continuous centrifugal decanters are normally horizontal shaft centrifuges type. They consist of an inner cylindrical drum perforated in certain portions and provided externally with a spiral pitch but with variable height. This spiral follows the contours of the second
drum, which is concentric with the first. The two drums rotate in the same direction but at different speeds, the inner drum having a higher speed than the external one, thus ensuring the function of cleaning the drum by means of the screw within. This assembly is driven by means of a motion transmission system by an electric engine with a nominal speed of 3000 rpm. The entire assembly is supported by a frame made of a welded structure. The 3D model of this equipment is shown in Figure 1.

3.2 Building the Ontology

Starting from the decanter centrifuge components (Figure 1), the ontology development of this type of equipment involved the classification of concepts and the development of class hierarchy shown in Figure 2. This analysis has revealed that a decanter centrifuge consists of three major components: the separator itself, the chassis and the drive system. After this phase the properties (slots) of each class were identified and set.

Once completed these steps, using the information visualization tools within Protégé, the centrifuge decanter ontology is shown in Figure 3. In this figure it is clearly highlighted the structuring of each main component of the decanter. Through the relations between the entities of each class one can easily obtain the lists of materials useful in their subsequent acquisition phase. Using this ontology to structure a family of such equipment allows the structuring of a knowledge base specific to this field of equipment. Filling this knowledge base with concrete rules of information processing, for example the Jess rules (Friedman-Hill, 2002), this package can be a useful tool in the design of other similar equipment.

4 CONCLUSIONS AND FURTHER RESEARCH

In this article we focused our attention on the application of ontology engineering methods in the field of wastewater treatment equipment of the centrifugal separators type. The results presented show that starting from the 3D model of the product one can structure an ontology that can easily become the base of useful tools in the design of similar products.
Once the ontology is structured, future research will be directed towards completing the ontology with Jess rules packages that can be used when approaching the issue of choosing certain components of such equipment, starting from some concrete specifications.

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