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Ontology Model for Assembly Process Planning Knowledge

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Abstract - **Assembly process planning is a highly knowledge-intensive work. As collaborative design and manufacturing is getting increasingly popular especially for complex assembly products, assembly process planning knowledge model should be comprehensive, recognizable and reusable. Ontology meets the requirements as a semantic tool providing a source of shared and precisely defined terms that can be utilized to describe both knowledge and concepts. Many researchers have studied the ontology modeling for assembly process planning domain and they mainly focus on the geometry information, tolerance type and manufacture environment respectively. This paper presents an assembly process design knowledge ontology considering assembly requirement, spatial information, assembly operation and assembly resource. It has covered almost every important concept related to assembly process planning knowledge.**

Keywords - **Assembly process planning, knowledge, ontology modeling**

I. INTRODUCTION

Assembly process planning (APP) is highly knowledge-intensive, involving assembly sequence planning, assembly path planning, resources and tools choosing, etc[1]. Modeling knowledge of assembly process planning is the foundation of decision-making mechanism. Study on acquisition, management, retrieval, sharing and reusing of knowledge is becoming increasingly important. As collaborative design and manufacturing is getting increasingly popular especially for complex assembly products. APP knowledge model should be comprehensive, recognized and reusable. This requests a knowledge modeling tool to be extendible and be able to make precise definition [2].

Ontology is a type of semantic tool providing a source of shared and precisely defined terms that can be used to describe both knowledge and concepts [3]. Ontology can be expressed in standard formal languages like XML which would ensure the sharability and cooperation. These characteristics make ontology a notable knowledge modeling tool in many domains like medical science [4], digital library [5], manufacturing [6], etc. Ontology modeling for APP knowledge has always been the research focus. Fiorentini[7] et al. showed that the ontological assembly model can help in achieving various levels of interoperability as required to enable the full potential of Product Lifecycle Management (PLM).Kim[8] et al designed a collaborative assembly design and information-sharing environments called Assembly Design Browser based on assembly design ontology model. Designers are no longer merely exchanging specific geometric data, but rather more knowledge about design and the product development process [9]. Ontology fits all the requirements of APP knowledge modeling.

II. OVERVIEW OF RELATED RESEARCH

A. Ontology

An ontology is the representation of knowledge based on conceptualization in a formal and explicit manner [10], in another word, explicit, formal specifications of terms in the domain and of the relations among them. The advantage of ontology is that it offers the concepts and their relations in a domain in a commonly agreed and formal expression that is machine-readable [11] and it has the reasoning capability that makes the implicit information explicit [12].

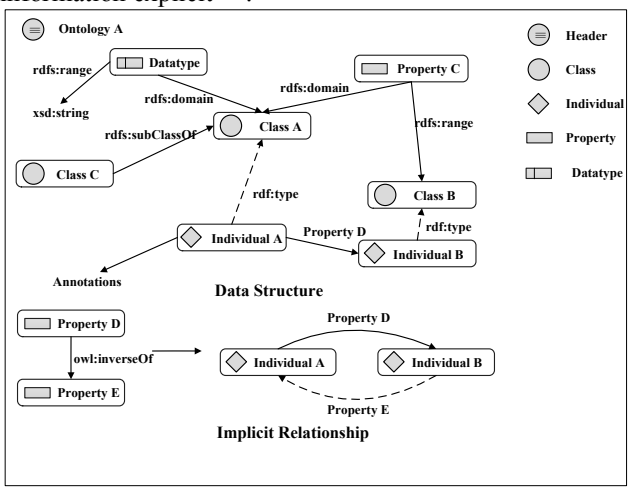

Fig.1.Sketch of ontology model

Ontology models are expressed as documents like OWL DL (Web Ontology Language - Description Logic). Take the OWL document as an example [13], each document consists of an ontology header, annotations, classes and property definitions (more formally referred to as axioms), facts about individuals, and datatype definitions, as Fig.1 shows. An ontology header is a resource that represents the ontology itself. Annotations are statements (triples) that have annotation properties as predicates. A class describes a set of resources that share common characteristics or are similar in some way which is used to define a concept. Individuals are instances of classes and are linked to classes via properties. A Property is a resource that is used as a predicate in statements that describe individuals which can be used to state relationships between individuals, or between individuals and data values. Datatypes in OWL represent ranges of data values. OWL 2 allows you to define your own

complex datatypes that are explicitly enumerated or defined using facet restrictions (value range restrictions).

B. Ontology Modeling for Application Domain

There are some modeling methods for practical application domain based on ontology that have made significant progress like TOVE (Toronto Virtual Enterprise) method for engineering product and design[14], Skeletal Methodology proposed by Mike Ushold and Micheal Gruninger[15], KACTUS(Modeling Knowledge about Complex Technical Systems for Multiple Use) Project Method developed in Esprit Project[16], etc. These methods were summarized through reverse engineering in independent cases in the background of diverse domain and each of them had special emphasis. But a common methodology does not exist yet considering differences in the specific field and concrete engineering. There are five principles provided by Gruber [17] in 1995 generally believed to be very influential:

(1) Clarity: An ontology should effectively communicate the intended meaning of defined terms and definitions should be objective.

(2) Coherence: An ontology should be coherent: that is, it should sanction inferences that are consistent with the definitions.

(3) Extendibility: An ontology should be designed to anticipate the uses of the shared vocabulary. It should offer a conceptual foundation for a range of anticipated tasks, and the representation should be crafted so that one can extend and specialize the ontology monotonically.

(4) Minimal encoding bias: The conceptualization should be specified at the knowledge level without depending on a particular symbol-level encoding.

(5) Minimal ontological commitment: An ontology should require the minimal ontological commitment sufficient to support the intended knowledge sharing activities.

The principles for modeling a standard knowledge ontology based on those methodologies and principles mentioned could be summarized as: striving to cover all the content in the domain, describe all the concepts of data model and function model as well as the relationships, transformations and operations between the concepts in common definitions; Ensuring the correctness, normalization and simplicity of the knowledge model so that uniform knowledge base could be built which is the base of accessible and efficient data exchanging in later applications.

C. Related Research

Ontology has been used to model assembly knowledge domain knowledge in various researches already. Ontology-based researches take advantage of the capabilities to structure concepts and to connect them with part models, and make use of reasoners to set up inference rules to ensure the consistency of the assembly description or extract information that is not readily available in the dataset describing an assembly, and some researchers describe geometric features of entities unanimously utilizing standard specifications.

Kim[8]et al have developed an assembly design (AsD) ontology to describe the specification of assembly design. Investigated terms included Product, Assembly, Assembly Component, Part, Sub-assembly, Assembly Feature, Form Feature, Joint, Joint Feature, Mating Feature, etc. The definitions for assembly design terms were analyzed by Kim. For example, the definition of an assembly feature in engineering design was “a group of assembly information”, which included form features, joint features, mating relations, assembly/joining relations, spatial relationships, material, engineering constraints, etc. The AsD ontology model was built based on these concepts. In the model, six classes of assembly design concept were defined as shown in Fig.2: Material, Product, Feature, Spatial Relationship, Manufacturing and Degrees of Freedom. The concept of Product included Part and Assembly, the Feature concept included Feature for Part and Feature for Assembly, the Manufacturing was designed to include Manufacturing Process and Joining Process. The assembly design ontology model was designed as shown in Fig.2 after further classification and subdivision.

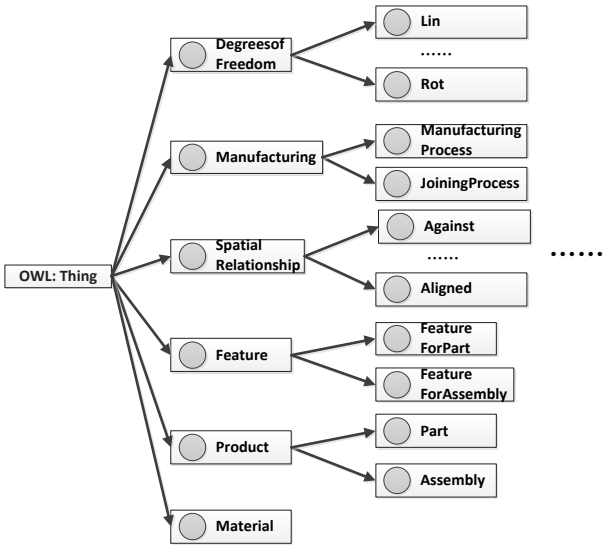

Fig.2.Part of AsD ontology class hierarchy.

The AsD model also included properties that represent class characteristics, domains, and ranges that represent class relationships as well as inference rules to query AsD information selectively like the assembly relation and spatial relation of chosen parts as well. This AsD formalism was also used in Assembly Design Browser-a collaborative assembly information-sharing environments because of the sharing and reusability of ontology.

However, many important concepts were still left implicit or not defined in this assembly process ontology model, implied assembly constraints, and tolerance cannot be easily obtained and expressed. While Krima's work[18][19]focused on the geometry data informational in ontology model.

Krima and Barbau[18][19] et al. proposed a way to enable the exchange of product data through a product lifecycle based on ontology between different designers and technologists. The ontology model is called OntoSTEP in their work using OWL-DL (Web Ontology Language - Description Logic) to describe the Standard for Exchange of Product model data (STEP) (ISO 1030)[20].STEP mainly focuses on product management data and geometry information still evolving to meet the needs of modern Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Product Data Management (PDM) systems. The STEP APs are defined using the EXPRESS (ISO 10303-11)[21] language which is developed to enhance product modeling and provide support to describe "the information required for designing, building, and maintaining products." The concept of entity in EXPRESS is similar to the concept of a class in object-oriented modeling. After translating the main concepts in EXPRESS into ontology, three entities were described: product, product category and product related category. These entities and instances of entities mapped respectively to OWL classes and individuals, detailed geometry data informational could then be described in the ontology model. In order to get better descriptive power, Krima built additional concepts in the model like Data Type, Aggregations, Select, Enumeration, Abstraction, Inheritance and Uniqueness Clauses to define the non-geometry information describe in EXPRESS.

In a given example by Barbau and Krima[18]et al., STEP AP203 was used to create a 3D CAD model of a product, while CPM(Core Product Model) and OAM(Open Assembly Model)were used to represent the functional decomposition of this product and the relationships between the parts. After geometric definition, integration of geometry and non-geometry information, the model designed could be stored in ontology and queries about retrieving the parts that are connected to a particular part via a fixed connection could run successfully.

Their work covers a larger description of a product with an ontological description incorporating the geometry levels, structure levels and even function levels in a unanimous approach by using international standard. But the authors showed that not all concepts of STEP could be rigorously defined which would lead to limitations in detecting inconsistencies because of the compatibility. The practical manufacture environment information like assembly process information and resource information is not considered enough in their work as well as the tolerance. Related research by Zhong[19] et al. focused on the assembly tolerance which showed that assembly tolerance types could be automatically generated based on ontology.

Zhong[22] et al. constructed an extended assembly tolerance representation model by introducing a spatial relation layer aiming at reducing the uncertainty and supporting the semantic inter operability in assembly tolerance specification design. The assembly tolerance representational ontology model consisted of three layers: part layer, assembly feature surface layer and spatial relation layer. The class structure in assembly tolerance representational ontology model is shown in Fig.3.

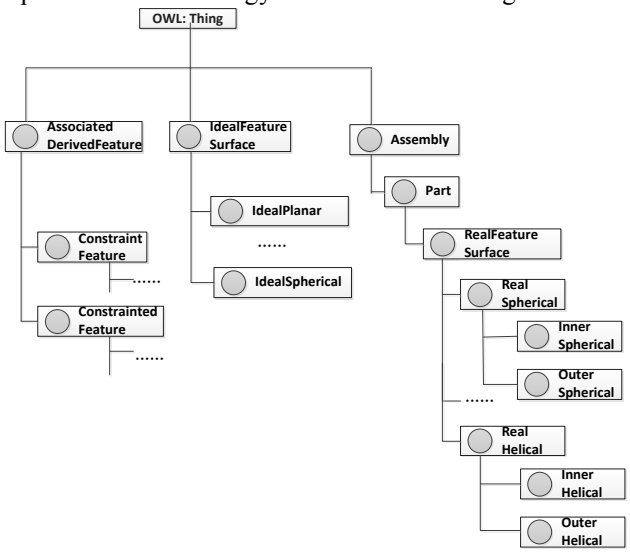

Fig.3.Classes in the ontology model for assembly tolerance representations

Assembly tolerances mainly included geometrical tolerance, angle tolerance, and linear dimensional tolerance. Geometrical and dimensional tolerances of parts can be determined by the assembly tolerances of the corresponding product. The authors classified the tolerance types according to the number of associated datums. Tolerances not associated with datums but instead associated with ideal shapes were called form tolerance, including straightness, flatness, roundness, cylindricity, profile any line, and profile any surface tolerances. Tolerances needing one or more datums to control the scope of their changes were called positional tolerances, including circular run-out, total run-out, parallelism, perpendicularity, angularity, position, concentricity (coaxiality), symmetry, angle, and linear dimensional tolerances. Following consideration of the functional tolerances, the ontology model also covered spatial relations. These were defined to be the Object properties used to connect certain geometry elements. Then this model could describe assembly tolerance explicitly. With this ontology model and SWRL rules defined, assembly tolerance types could be automatically deduced.

Lemaignan and Siadat[23] et al. presented an ontology model of manufacturing domain called MASON(MAnufacturing's Semantics ONtology) aimed to draft a common semantic net in manufacturing domain. MASON emphasizes data formalization and sharing particularly in an open manufacturing environment. Three kinds of classes were defined in this work: (1) Entities, are the common helper concepts which provide the concepts to specify the products. (2)Operations, relate to process description which cover all processes linked to manufacturing in a wide acceptation. (3) Resources, stand for the whole set of manufacturing linked resource. They also defined properties to connect the concepts

considering the real assembly process planning works. It has already been used in Automatic Cost Estimation research as well as Multiagent module for Manufacturing system. This work provided shared and precisely defined knowledge and concepts as shown in Fig.4.

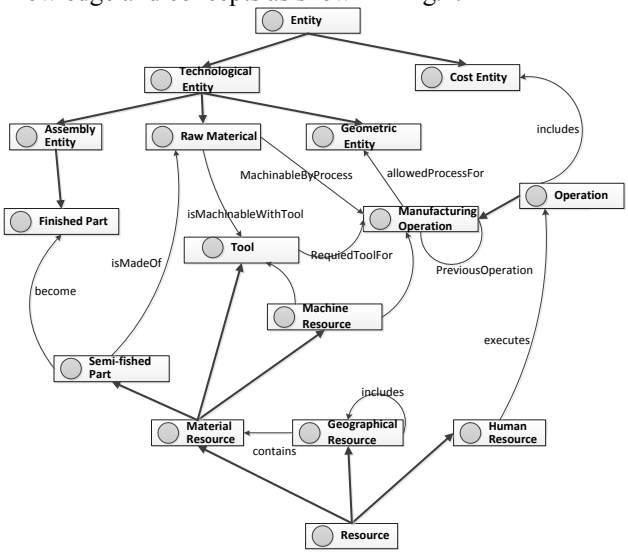

Fig.4.Overview of the ontology's main classes and object properties[23]

Lemaignan's work presented a different view to define the domain of assembly which focuses on the practical manufacturing condition.

III. ANONTOLOGY MODEL FOR APP KNOWLEDGE REPRESENTATION

This paper aims at proposing an ontology model for APP knowledge in order to ensure consistency of interface definitions among different designers and technologists in a collaborative design and manufacturing environment[24]. Based on the principle of comprehensiveness and reusability, this paper subdivides the content and necessary information of APP knowledge into assembly requirement, spatial information, assembly operation and assembly resource, these concepts need to be accurately defined in a common way. The APP knowledge ontology model is as shown in Fig.5

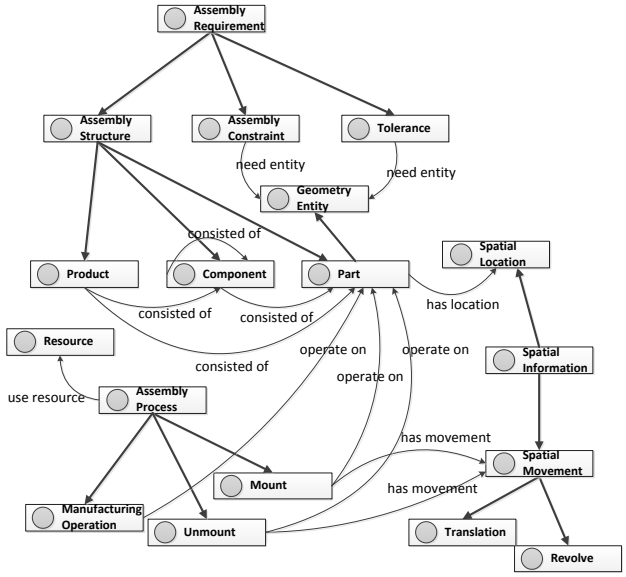

Fig.5.Main classes and object properties of APP knowledge model

The assembly requirement is the critical information designers attempt to present. It contains assembly structure, geometry entity, assembly constraint and tolerance. In the ontology model, the assembly structure is used to describe structural relationships within a product based on the concepts of part, component and product as well as the relationships between these concepts. Geometry entity requires to be defined unambiguously as the carrier of assembly constraint and tolerance, this work could refer to the OntoSTEP[20] which could define geometrical elements in the use of international standard. Assembly constraint and tolerance can then be defined as distance and angle requirement between two certain geometrical elements. This would greatly enhance the ability to describe tolerance and other geometry information.

Spatial information presents the location, pose and movement of objects in 3D space which is closely connected to the assembly path planning and assembly sequence planning. The location and pose of objects could be completely defined by the absolute coordinate and the relative coordinate fixed on the part if deformation is not considered. Then the spatial motion could be resolved into the Translation of original point and the revolution around the axes of relative coordinate. These definitions could help Assembly Path Planning in the future.

Assembly operations are the basic elements of assembly process. These concepts defined with standard terms are linked to concepts of available resource aiming to describe the assembly capacity of a certain manufacture environment. This part should cover all the operations in assembly processes and the resources needed. Furthermore, the ability of certain operations and resources could be appended to this APP knowledge ontology model making it possible for automatic assembly process planning.

The ontology model has covered important concepts of assembly process knowledge, and it could clearly express geometry and non-geometry information

including tolerance, assembly structure, assembly process and resources that are not considered integrated before. A lot of work remain needed to finish this model and to realize its application. But it is worthy to be developed.

IV.CONCLUSION

Assembly process planning knowledge modeling is getting critically important. As this paper shows, ontology modeling for assembly domain has achieved many significant results. Most researchers focus on tolerance, practical manufacturing condition or spatial motion adequate consideration in their work. This paper presents an assembly process design knowledge ontology model covering all the important concepts related to assembly process planning like assembly requirement, spatial information, assembly operation and assembly resource. A lot of work remain needed to be completed, but this model would greatly push the development of the assembly process planning automatically.

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