Ontological Approach to Share Product Design Semantics for an Assembly

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Abstract: The aim of this paper is to facilitate the transfer of product data semantics from Computer Aided Design (CAD) program to assembly process planning (APP) in product life- cycle. In this paper, an approach to capture, share and transfer assembly design semantic data from SolidWorks (SW) CAD software to assembly device (robot Sony SRX series) is proposed. The proposed approach is based, on its first stage, on defining and extracting assembly design semantics from a CAD model using SolidWorks Application Programmable Interface (SW- API). The second stage of the proposed approach includes sharing and integrating the extracted assembly design semantics with assembly robot device by using three-layer ontology structure. In this layered ontology, different types of ontologies are proposed for each layer: general foundation ontology for the first, domain ontologies for the second and application ontology for the third. Each of these layers aids in defining concepts, relations and properties in assembly design domain and APP domain. Ultimately, the proposed ontology will be used to integrate both domains in product-life cycle.

1 INTRODUCTION

During the last decades, the necessity of data sharing and integration among different users and applications in product-life cycle has been increased. For example, the product / assembly design semantic data stored in a specific CAD model needs to be delivered to different CAD softwares or to be analyzed by different softwares.

Two methods have been proposed to facilitate product / assembly design data transfer among different applications and users: external and internal (Miao et al., 2002). In external method product data is transferred using a standard neutral data format, such as IGES or STEP, while in the internal method API (application programmable interface) functions have been used to recognize and extract product design data from CAD model. Both methods have some limitations in sharing product / assembly data. In both methods data has been transfer from user to user or from application to application but not from domain to domain. Another limitation is the data lost during conversion from one format to another format in the external method and the syntactical transfer of data in the internal method. In order to overcome those limitations, ontology approach to share product / assembly design semantics has been proposed.

Recently, the ontology and semantic Web technology has been widely applied in integrating product design and different applications in product-life cycle. Ontology can be regarded as "*a data model that represents a domain and is used to reason about the objects in that domain and relations between them*" (Gruber, 1993). Ontologies have been used to capture and share product design knowledge, to integrate engineering applications and to solve interoperability problems (Patil et al., 2005). Ontologies specify "*a domain-specific vocabulary of entities, classes, properties, predicates, and functions, and a set of relationships that necessarily hold among those vocabulary items*" (Fikes and Farquhar, 1999). Ontological approach has been used either in modelling or retrieving product / assembly design semantics generated during design process. By ontology querying, data can be retrieved and by ontology reasoning, data that are not expressed explicitly can be derived from the ontology.

In this paper, a proposed approach, based on ontology, to integrate SolidWorks (SW) CAD

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software in assembly design domain and assembly robotic device in Assembly Process Planning (APP) domain is introduced. The integration framework of the proposed approach is illustrated in Figure.1. In Figure 1, the first stage of integration is to extract and model assembly design data from SW- CAD in assembly design domain (using SW- Application Programmable Interface (SW-API)), and processes and resources data from assembly robotic device in the APP domain. The second stage includes sharing the extracted assembly design data by assembly design ontology and processes and resources data by APP ontology. The integration of the assembly design domain and APP domain will be achieved by ontological mapping between assembly design ontology and APP ontology, which represents the third and last stage in the integration framework.

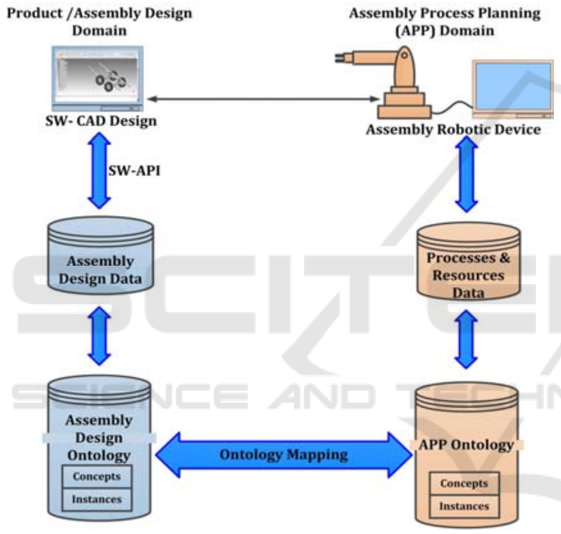


Figure 1: Integration framework between assembly design and APP.

This paper is mainly focused on the first and second stages of the integration framework. This paper is structured as follows: Section 2 introduces briefly assembly design semantic model based on assembly features. Section 3 introduces the proposed ontology for sharing the extracted semantic data from the previous section, and integrating SW CAD software with assembly robotic device. Section 4 draws a conclusion and provides a summary.

2 ASSEMBLY SEMANTIC MODEL

The most representative assembly design modelling methods are based on features (Shah and Rogers, 1993), constraints (Ma et al., 2004) and assembly semantics (Liu et al., 2000). According to Liu et al. (2000) assembly semantics is defined as *"the abstract description of assembly relationships, which implies the constraint between parts, assembly rule, assembly knowledge and assembly action"*. In this paper, assembly semantic model, based on features, is developed (Figure 2) to model assembly design data extracted from SW- CAD software.

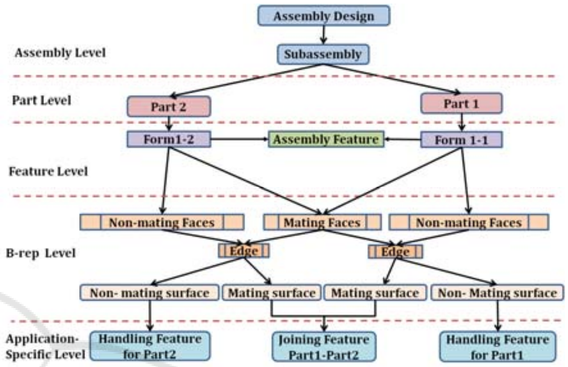


Figure 2: Assembly design semantic model.

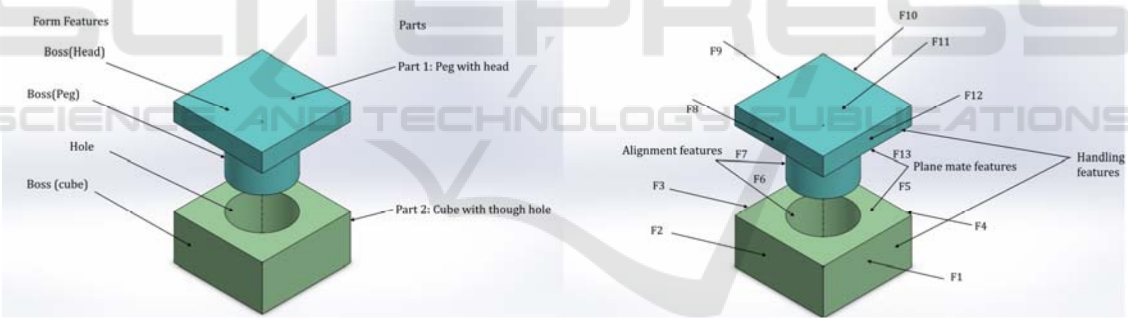
In Figure 2, a multi-level assembly semantic model is illustrated; each layer conducts different details about assembly design. Assembly and part levels concern about structural information of an assembly, each product is composed of several subassemblies, and each subassembly is composed at least from two parts. The feature level is concerned about geometrical and assembly knowledge enclosed in form and assembly features. Assembly feature is defined as an association between two form features from different parts in a product (Shah and Rogers, 1993), where form feature is defined as *"specific configurations on surfaces, edges, or corners of a part such as holes, slots etc. that carries some engineering meaning"* (Wingard, 1991).

Each part is composed at least of one form feature, which is associated with another form feature, from different part, via an assembly feature. The next B-rep entity level conducts more specific knowledge about geometrical entities involved into assembly relation. B-rep modelling decomposes a solid into its boundary surfaces or shells. Each shell can be decomposed into individual faces. Each face is described as a surface bounded by a loop of edges. Each edge is bounded by two vertices. In the B-rep level, each form feature is composed from mating faces (faces with assembly relations) and non-mating faces (faces that are not involved in any assembly relation). Mating and non-mating faces are decomposed further into mating surfaces and non-mating surfaces. The last level, which is the application-specific level, will assign specific functional features for each surface type to perform assembly processes.

Mating surfaces will be involved in joining processes (welding, screwing, fitting, etc.) so they will be a part of joining features, which are proposed by (Kim, 2003) to represent assembly/joining relations, and it includes joining entities, joining methods, constraints and groove shapes. The non-mating surfaces will be involved in handling processes (gripping, feeding and fixturing) so they will be known as handling features- "*characteristics that give the locations on an assembly component that can be safely handled by a gripper during assembly!*" (Van Holland, 1997). Further illustration for the concepts of the assembly semantic model is presented in peg and though-hole cube assembly example in Figure 3, the assembly semantics are illustrated in Figure 4 as well.

In Figure 3, a two-part assembly (part 1: rectangular head peg and part 2: cube with through-hole) is presented. The parts and form features of the assembly are indicated in Figure 3 a. In Figure 3 a, part 1 consists of two form features: the head and the peg. Part 2 consists also of another two form features: the hole and the cube. In Figure 3b, the two-part assembly is further decomposed into its elementary boundary faces (B-rep entity). The mating faces are indicated as plane mate features for rectangular faces (F13- F5) and alignment feature for cylindrical faces (F7 –F6). An example about handling features selected from the non-mating surfaces is also indicated (F12 from part 1 and F1 from part 2). The assembly semantic model for the two-part assembly is illustrated in Figure 4. A six-layer semantic model is presented, where the first layer is for the assembly, which is composed of parts and features in the second and third layers. The features are composed of the B-rep entities like faces, profile, centerlines, and so on in the fourth layer. The last two layers are for position/orientation and geometrical dimension and tolerances (GD&T). The position layer consists of reference line and reference point for each part, while the GD&T layer consists of dimensions and tolerances for each B-rep entity

Assembly data semantics include well- definition and usage of assembly design data. Practically,



(a) (b)

Figure 3: (a) Peg and though- hole cube assembly, parts and features (b) Peg and though- hole cube assembly, faces assembly features.

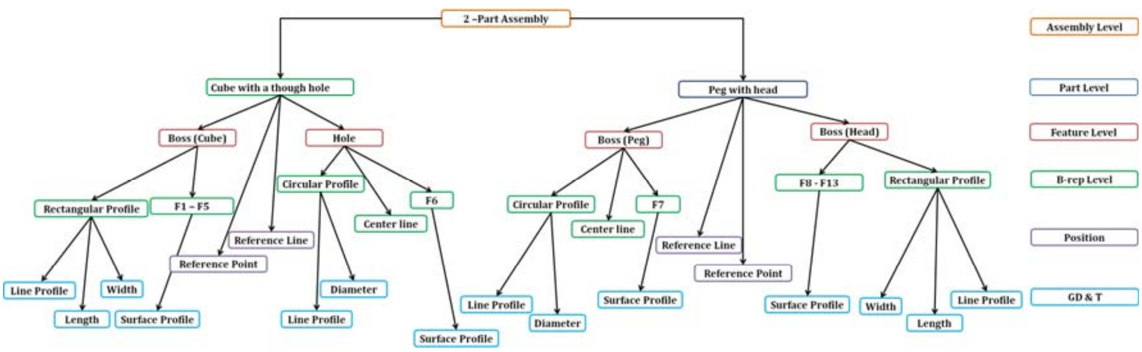


Figure 4: Assembly semantic model for the two-part assembly.

assembly data semantics, which is built upon assembly data, is represented by two layers: knowledge layer and instance layer. The knowledge layer describes the basic knowledge within any domain by using a set of generic concepts, relations between those concepts and axioms applied on relations. The instance layer, which is more specific layer, links product data into the knowledge layer by instantiating concepts of the knowledge layer. Figure 5 shows our proposed approach to create product data semantics by extracting product data (geometry, tolerance, kinematics and assembly design) from SW- CAD software using SW-API. The relation between the knowledge layer and instance layer is illustrated as well.

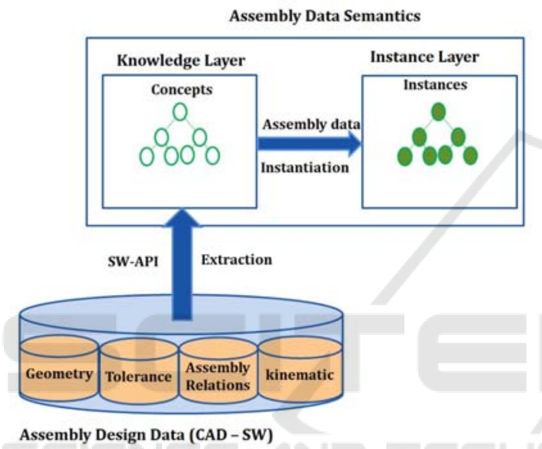


Figure 5: Relationship between assembly data and assembly data semantic knowledge and instance layers.

3 ONTOLOGY DEVELOPMENT

The literature points out that a significant amount of work has been done on the use of ontologies either to model assembly design data or to support integration between design and process in assembly. Lohse et al. (2006) proposed ontology to support selection of assembly resources and to support reconfigurablility of assembly system. Lanz et al. (2008) proposed ontology to capture design and process related assembly knowledge based on assembly feature concept. Delamer and Lastra (2006) developed an ontology to model assembly processes. Kim et al. (2003) proposed an assembly design ontology to support formalism of related assembly knowledge in product design. Demoly et al. (2012) proposed an ontology to capture the product design and assembly sequence planning knowledge. Mostefai et al. (2006) proposed ontology to capture the product design data to support the product development process. Zhan et al. (2008) and Zhu et al. (2009) proposed layered structure ontologies to integrate product design and assembly simulation.

In this paper, a three-layered architecture of engineering ontologies in product design and APP is proposed (Figure 6). The proposed structure layered ontology consists of:

- General Foundation Ontology (GFO)
- Domain Specific Ontology (DSO)
- Application Specific Ontology (ASO)

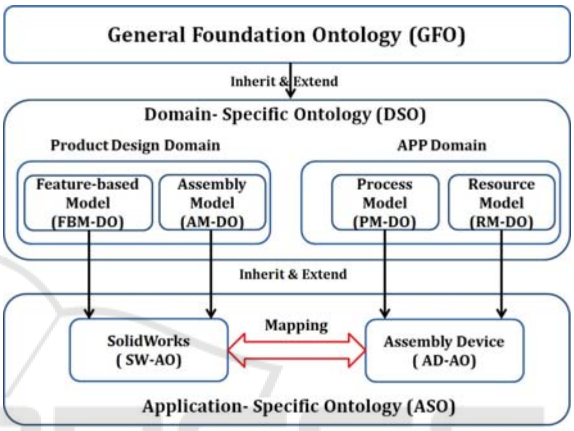


Figure 6: Three-layered architecture of engineering ontologies in product design and APP.

The GFO is the first upper layer ontology, which is designed to provide common concepts, such as *product*, *feature*, *material*, *process*, and *resource* which are inherited by the DSOs such as FBM-DO, AM-DO, PM-DO and RM-DO. The Domain Specific Ontologies represent the second level of the proposed architecture; those ontologies will add domain-specific concepts which belong to that particular domain. The third level is the ASOs (such as SW-AO and AD-AO); those ontologies will capture semantics specific to each application. Two applications have been included: SolidWorks as product design application and assembly robotic device (ex. high speed assembly robot Sony SRX series) as APP application. The knowledge transfer between different ASOs can be accomplished through mapping procedures which discovers similar or matching concepts and properties.

All of the ontologies are implemented by using the Protégé-OWL editor. In the following subsections; the three different ontologies of the layered ontology structure will be discussed.

3.1 General Foundation Ontology (GFO)

Foundation ontologies consist of generic, abstract, and high level concepts which can be applied to a wide range of domains. Foundation ontologies also provide a knowledge base for more specialized ontologies (Sanchez-Alonso and Garcia-Barriocanal, 2006). The GFO contains the general key concepts, which are common and applied to any of the domains in product design and APP. The concepts defined in GFO are *product*, *feature*, *material*, *process*, and *resource* (see Figure 7).

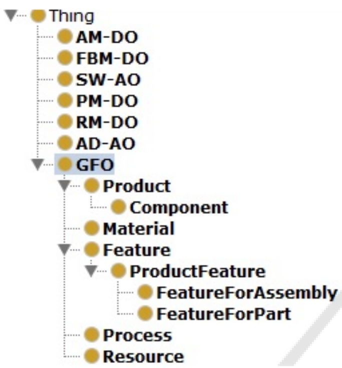


Figure 7: Class hierarchy and concepts of the GFO.

The concepts in the GFO ontology have attributes, which will be inherited by the different domain ontologies. For example, the *Component* subclass, which describes the basic structural design entity under the *product* class, will be further inherited by FBM-DO and SW-AO. FBM-DO will further embody Component with *Assembly*, *Subassembly* and *Part* subclasses. The same will be applied to the *Feature* class and its subclasses: *FeatureForPart* and *FeatureForAssembly*, which will be further inherited by the FBM-DO and SW-AO. The properties defined in FGO are: *is-a*, *is-a-part-of*, *is-composed-of* and *has-attribute-of*. The first two properties reflect the inheritance relations between different concepts. The last two properties define the relations between concepts and its attributes. Each of these ontologies will be discussed in the following subsections.

3.2 Domain Specific Ontology (DSO)

The DSO layer consists of four domain ontologies (DO). Two of those are in the product design domain, namely the Feature-based Model (FBM-DO), and the Assembly Model (AM-DO), and the other two are in the APP domain, namely Process Model (AM-DO) and Resource Model (RM-DO). Each DO reuses concepts and properties from the FGO and defines more specified, expanded and specialized concepts/ properties for a particular domain.

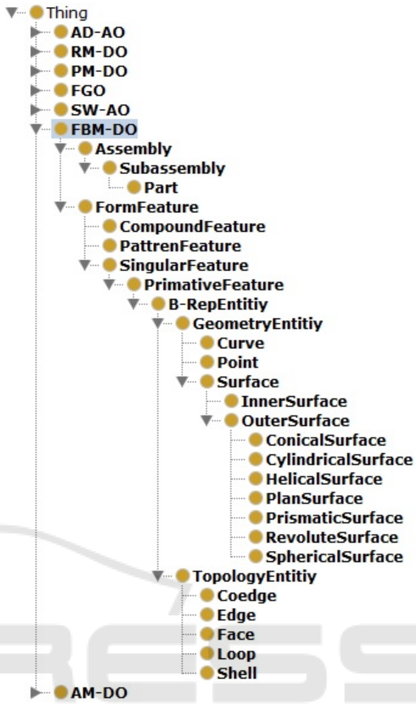


Figure 8: Class hierarchy and concepts of the FBM-DO.

The FBM-DO is created to capture knowledge about a product's structure and form domain. In Figure 8, the FBM-DO expands the product structure and geometry based on feature modelling. *Assembly*, *Subassembly* and *Part* classes represent the product basic structure, where the Subassembly is composed at least of two parts. The *Part* class is further decomposed into its features. Each part is composed at least of one form feature. The *FormFeature* class is decomposed according to complexity into: *PatternFeature*, *SingularFeature*, and *PrimitiveFeature*. *PrimitiveFeature*, which is considered as the basic form feature unit is further decomposed into *B-RepEntity* class, which will be decomposed further into the very basic geometrical and topological entities: *GeometryEntity* and *TopologyEntity*. *GeometryEntity* has attributes *Surface*, *Curve* and *Point*. The Surface class includes all different types of surfaces used in geometric modelers. *TopologyEntity* has attributes *Edge*, *Shell*, *Loop*, *Face*, and *Co-edge*.

AM-DO is created for assembly modelling as part of the product design domain (see Figure 9). If the FBM-DO represents the form attribute (geometrical and structural information) of the product design, AM-DO represents the behaviour of the design unit during assembly. AM-DO includes three major subclasses: *SpatialRelationship*, *DegreeOfFreedom*, and *AssemblyFeature*. *SpatialRelationship* expresses the relative positions of parts in an assembly in their final state. *DegreeOfFreedom* is used to describe the motion (translation and rotation) of parts during assembly. The third subclass, *AssemblyFeature*, is composed of *Mating*, *Alignment*, *Handling*, *Joining*, and *Tooling* features. The *AssemblyFeature* class introduces necessary assembly design information to establish a link with assembly processes and resources for APP.

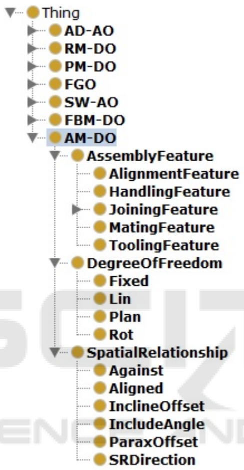


Figure 9: The class hierarchy and concepts of the AM-DO.

Joining features, with further specializations (welding features, fastening features etc.); represent a link for integration with joining processes. Handling and tooling features represent a link for integration with assembly resources. Handling features represent the geometrical characteristics of the part that are needed to determine the required assembly transporting resources such as fixture, feeder, and gripper. Tooling features represent the geometrical characteristics of the part's shape that are needed to determine the required assembly tooling resources. An example of the tooling features is the shape and size of the screw's head, which are required to determine the suitable tool.

The next two DSOs are the PM and the RM of the APP domain. The PM-DO is illustrated in Figure 10, where the process class in GFO is expanded and inherited by PM-DO into *AssemblyProcess* and *ManufacturingProcess* classes. The *AssemblyProcess* class is further expanded into *JoiningProcess* and *HandlingProcess* classes. The *JoiningProcess* class is composed of subclasses representing different joining processes in APP such as *Welding* and *Fastening*. The *HandlingProcess* class is composed of *Gripping*, *Feeding*, and *Fixturing* subclasses.

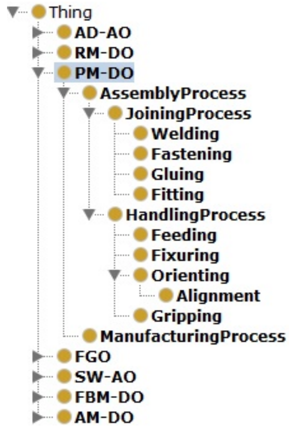


Figure 10: The class hierarchy and concepts of the PM-DO.

The RM-DO represents manufacturing and assembly resources in APP (Figure 11). The *AssemblyResource* class is further decomposed into several subclasses according to complexity from *Enterprise* and *Factory* subclasses into *Area*, *Line*, *Cell*, *DeviceCombination*, and *IndividualDevice*.

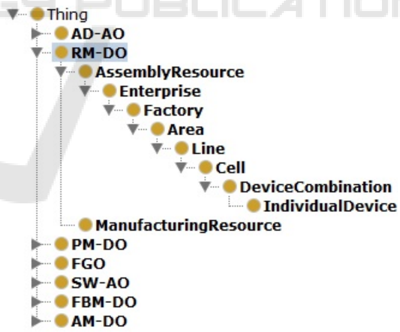


Figure 11: The class hierarchy and concepts of the RM-DO.

The *IndividualDevice* subclass is further inherited by AD-AO in the ASO layer, which will be discussed in the next subsection.

3.3 Application Specific Ontology (ASO)

So far, the ASO represents the lowest/ level of the proposed ontology. ASO defines more specified, expanded and specialized concepts/properties for a particular application. ASO is used to transfer product data semantics between different engineering applications. In this paper, two ASOs are developed: SW-AO to share product design data semantics from SolidWorks CAD software, and AD-AO to utilize assembly processes and resources in converting product data semantics into an assembly process plan for performing assembly of a finished or semi-finished product.

SolidWorks, as a commercial product design package, has been widely used as a 3-D geometrical modeler in various product life-cycle and product development applications. SW-OA (Figure 12) inherits and expands concepts from ontologies at higher levels such as *FormFeature* from FBM-DO and *MatingFeature* from AM-DO. For example, *FormFeature* from FBM-DO inherits and expands into *Round*, *Revolve*, *Hole*, *Fillet*, *Extrude*, and *Chamfer* under *ShapeFeature* class in the SW-AO. *MatingFeature* from AM-DO inherits into *Concentric*, *Tangent*, *Perpendicular*, *Parallel* and *Coincident* under *AssemblyConstriants* in the SW-AO. SW-AO also defines unique concepts, which are only used in SW. An example of the unique classes in SW-AO is the *DimXpertManger*. This class is composed of several subclasses such as *ReferenceManger*, *GeometricTolerance*, and *Dimensions*. The *ReferenceManger* subclass determines positional parameters of the features. Data for lines and points have been determined under *Datumline* and *DatumPoint*, respectively. The two subclasses *GeometricTolerance* and *Dimensions* include all different types of dimensions and tolerances, which have a direct impact on geometrical variations in the assembly design.

The SD-AO (Figure 13) represents robotic assembly device and consists of several units, which are represented by subclasses: *HandlingAndOrientingTools*, *JoiningTools*, *ToolChanger* and *Robot*. The first two subclasses include all different tools that will be used in handling, orienting and joining parts during assembly. The *FixturingTool*, *GrippingTool* and *FeedingTool* are subclasses for the *HandlingAndOrienting* class. Different types of gripping tools as *PincerGripper*, *MagnetGripper*, *VacuumGripper* and *FingerGripper* under *GrippingTool* subclass. Attributes and properties could be defined for each gripper type such as gripping range, gripping power and force. *JoiningTools* includes *WeldingTool*, *PressingTool*, and *ScrewingTool*. The Robot class includes different robots that are commonly used in robotic assembly devices such as ScaraRobot, MobileRobot, and HexapodRobot.

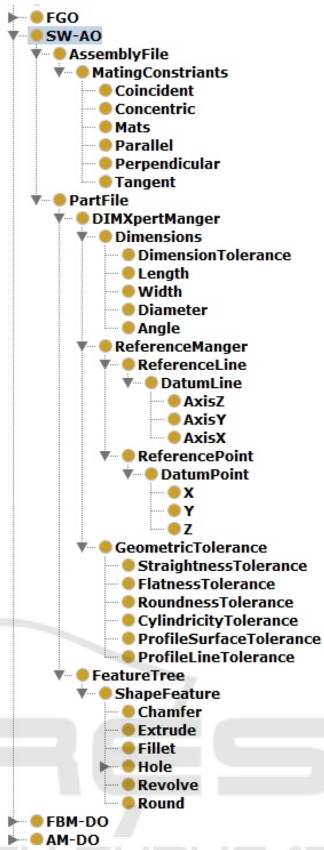


Figure 12: Class hierarchy and concepts of the SW-AO.

The integration between product design domain and APP will be performed through a mapping procedure between SW-AO and SD-AO. The processes and resources represented by different tools in SD-AO will be selected according to the product design semantics represented in SW-AO. For example, a width dimension in Dimensions class in SW-AO may determine the type of gripping (whether it is finger gripping or magnet gripping) in SD-AO. Another example is that a type of a hole in *ShapeFeature* class in SW-AO might determine the joining tool in SD-AO.

The ontology part in this paper will be expanded in further work by defining axioms for the FDO and properties for the DSOs and ASOs. Also a detailed mapping procedure based on defined properties of SW-AO and AD-AO has to be performed in the future work.

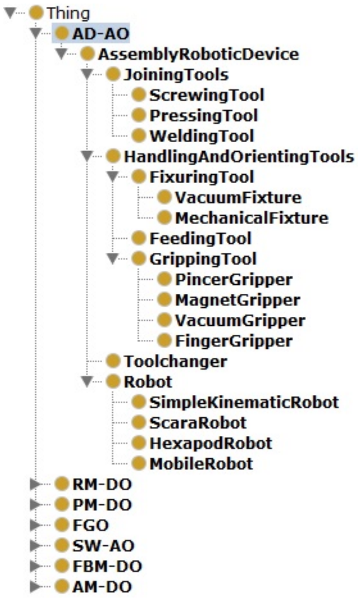


Figure 13: Class hierarchy and concepts of the SD-AO.

4 CONCLUSIONS

In this paper, a proposed approach for extracting and integrating product design semantics to APP is proposed. The proposed approach based on extracting the related assembly design knowledge by using SW-API, and on structure-layered ontology for sharing and integrating product design semantics with APP. Future work includes upgrading the structure-layered ontology by developing the ontological mapping procedure between assembly design domain and APP.

REFERENCES

Delamer, I. M., & Lastra, J. L. 2006. Ontology modeling of assembly processes and systems using Semantic Web Services. International conference on industrial informatics (pp. 611-617). IEEE.

Demoly, F., Matsokis, A., & Kiritsis, D. 2012. A Mereotopological product relationship description approach for assembly oriented design. Robotics and Computer-Integrated Manufacturing, 28, 681–693.

Fikes, R., and Farquhar, A., 1999. Distributed Repositories of Highly Expressive Reusable Ontologies, IEEE Intelligent System, vol. 14, no. 2, pp.73-79.

Gruber, T. R., 1993. Toward Principles of the Design of Ontologies Used for Knowledge Sharing, International Workshop on Formal Ontology in Conceptual Analysis and Knowledge Representation.

Kim, K. 2003. Assembly operation tools for. Assembly operation tools for e product design and realization. PhD dissertation thesis. University of Pittsburgh.

Lanz, M., Garcia, F., Kallela, T., & T, R. 2008. Product-process ontology for managing assembly specific knowledge between product design and assembly system simulation. In S. K. Svetan Ratchev, Micro-Assembly.

Technologies and Applications (Vol. 260, pp. 99-108). Boston: Springer.

Liu, Z. Y., Tan, J. R., Zhang, S. Y. and Jian, Z. F, 2000. Design semantics of assembly modeling in virtual environment: expression, transfer and transformation, Chinese Journal of Computers, Vol. 23 No. 11, pp. 1208-14.

Lohse, N., Hirani, H., & Ratchev, S. 2006. Equipment Ontology for modular reconfigurable assembly systems. International journal of flexible manufacturing system, 17, 301-314.

Miao, H. K., Sridharan, N., & Shah, J. J., 2002. CAD-CAM integration using machining features. International Journal of Computer Integrated Manufacturing.

Mostefai, S., Bouras, A., & Batouche, M. 2006. Effective collaboration in product development via a common sharable ontology. International Journal of Computational Intelligence, 206-212.

Patil, L., Dutta, D., and Sriram, R., 2005. Ontology-Based Exchange of Product Data Semantics, IEEE Transactions on Automation Science and Engineering, vol. 2, no. 3, pp. 213-225.

Sanchez-Alonso, S., & Garcia-Barriocanal, E. 2006. Making use of upper ontologies to foster interoperability between SKOS concept schemes. Online Information Review, 30(3), 253-277.

Shah, J. and Rogers, M. 1993. Assembly modeling as an extension of feature-based design. Research in Engineering Design, 5(3-4), pp.218-237.

Van Holland, W. 1997, Assembly features in modelling and planning, PhD thesis, Delft University of Technology.

Wierda, L., 1991. Linking Design, Process Planning and Cost Information by Feature-based Modelling. Journal of Engineering Design, 2(1), pp.3-19.

Wingard, L. 1991, Introducing Form Features in Product Models, A step Towards CAD CAM with Engineering Terminology, Licenciate Thesis, KTH: Royal Institute of Technology.

Zhan, P., Jayaram, U., Jayaram, S., 2008. A Semantic Approach for CAD/CAE Integration, Proceedings of 2008 NSF Engineering Research and Innovation Conference.

Zhu, L. J., Jayaram, U., Jayaram, S., and Kim, O., 2009. Ontology-Driven Integration of CAD/CAE Applications: Strategies and Comparisons, ASME IDETC/CIE Conference.