Design Ontology Based on Geometry APIs and its Application

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***Abstract*—Design ontology is playing important roles in collaborative and knowledge-intensive design. The ontology based on geometry APIs and surface-behaviors was proposed to build the semantic connection among functions, behaviors and structures, which further refine product design FBS models. The lightweight network transmission and the rapid product design can be finished by the design ontology. The cases proved that the representation of design knowledge based on geometry API ontology can be easier to share and access.**

***Index Terms*—design ontology, function-behavior-structure, geometry APIs, surface-behaviors.**

I. INTRODUCTION

Modern product design is multi-party collaborative and knowledge-intensive. The emergence of the web-based and ontology technology makes these needs become possible by sharing and reusing team design knowledge. Though computer-aided design tools such as AutoCAD, PRO/E, CATIA, and UG as conventional design means have provided us with a large-scale electronic design documents, they are merely aimed at the integration of geometric data but not design knowledge-oriented. How to represent, access and share the design knowledge by ontology in the computer-aided design environment is extremely meaningful.

This paper focuses on the representation of product design ontology based on geometry APIs on the basis of FBS model and four domains of axiomatic theory [1, 2] and its application on sharing and accessing the design knowledge about customer requirements, functions, behaviors, structures, process, etc. Geometry APIs[3] as objects in CAD are the logic units conforming to designer intuitive thinking in product modeling process, which also known as CAD services can ensure interoperability between heterogeneous design tools in a distributed environment[4]. The ontology system with geometry APIs as its core sets up semantic correlation among attributes, thereby breakthroughs the mandatory word convention.

The rest of the paper is organized as follows. Section 2 reviews some previous studies related to product design ontology. Section 3 introduces the design ontology with geometry APIs as the basic elements. Its application on product design is given in section 4. A gear pump as an example is demonstrated in section 5. In section 6, the future work is given.

II. BACKGROUND

The most broadly used definition of ontology is given by Gruber: Ontology is a formal specification of a conceptualization. A conceptualization is an abstract simplified view of a domain that describes the objects, concepts and relationships between them [5]. Ontology should be reusable and shared across several applications, and the common understanding of a domain is defined by using ontology, which can be used to support inter-human and inter-organizational communication, to support the semantic interoperation of different software systems [6]. The ontology on assembly design, manufacture, function, structure, universal design, etc. has been discussed extensively in product design fields.

The most important work of product design mainly includes functional design, schematic design (behavioral design), layout design, shape or preliminary structural design. Gero early established the FBS (Function-Behavior-Structure) model of product design and proposed the product design ontology and design process ontology based on FBS [7-10]. A knowledge representational scheme for functions called Function-Behavior-State (FBS) model is proposed by Yasushi [11]. Sharing designer's intention called design rationale (DR) is important, so Horváth focuses on modeling DR of supplementary functions to aim at establishing the ontology for capturing such designer's knowledge systematically [12]. Tudorache referred to the components, connections, systems, requirements and constraints as engineering ontology [13]. Christel proposed the feature ontology in the stages of design involving mapping a specified function onto a realizable physical structure [14]. Kyoung gave the hierarchy of assembly design ontology classes include feature, spatial relationship, material, manufacturing, etc. [15]. Li discussed function ontology, behavior ontology, feature ontology, mating relation ontology, component ontology in the layered FBSO model [16]. Kitamura proposed the systematic description based on the function ontology in the conceptual design phase [17]. The design ontology on device-centered and process-centered was discussed in artifacts knowledge modeling [18]. Oren developed a descriptive model of the thinking process in design including what stimulates creativity and how designers create design, and the experiments have shown that behaviors stimulated more than functions [19]. The above-mentioned ontology had not the more detailed analysis of the behavior entities, which are still a kind of text description or word convention.

III. PRODUCT DESIGN ONTOLOGY BASED ON GEOMETRY APIS

A. Design FBS Model

Product can be decomposed into equipments, components and parts from the combination perspective. Their three-dimension model is decomposed into a tree or hierarchical mode according to the geometry elements such as features and geometry APIs in CAD, as shown in figure 1.

In the above decomposition, there are two kinds of modeling APIs: geometric topology APIs and geometric body APIs.

The decomposition elements from features to surfaces even datum exist to satisfy certain design requirements as functions. Functions are usually represented with verb-noun pairs, verb means function semantics, noun means the objects in the verb. There is a correlation among all functions that some functions are attached to the core function besides the hierarchical combination, and both are a kind of whole-part relationship.

Functions and structure features are artificial convention relations. The concept of behavior is introduced to decompose and quantify function to describe functions formally. Behaviors complete how the functions work, and functions are specifically expressed and implemented with series of behaviors in accordance with certain principles or rules. Functions are the subjective abstraction of behaviors with static characteristics and behaviors are the concrete realization of functions with dynamic characteristics [20]. Zhang summarizes the FBS schools in Australia, Japan, the United States and Europe and thinks that functions with the context have a certain degree of subjectivity and behaviors as a collection of states are in line with the stimulus-response mode, which are divided into kinematics behaviors, kinetics behaviors and static behaviors. Status values and time are as parameters of the former two categories called as dynamic behaviors, the external force is as input and the stress less than the material ultimate is as output in the static behaviors [21]. A dynamic behavior can be transformed into multiple static behavior frames. Only on the surface of certain structures can the static behaviors complete the appropriate action that manifest by a physical force, tension or surface visual. Behaviors of a product are formalized through physical forces on surfaces.

Definition A surface-behavior is the action bearing on the surface of a product structure, manifested as a physical force, curvature or a decorative pattern. All surfaces and their actions together constitute the main structure and functions of the product. If a surface-behavior is B, a surface is S, an action is A, a force is F, curvature is C, a decorative pattern is D, then $B=<S, A>$, $A=F|C|D$, S contains a surface shape describer and its parameters as a face entity, A is a vector force, a curvature scalar or a resource identifier.

Structures and behaviors are coupled with surfaces and their actions, actions are combined into abstract functions, and then structure features and functions are linked through the combination of a series of surface-behaviors, so the functions, behaviors and structures have the formal semantic and quantifiable relations, rather than link merely by the mandatory convention between functions and structure features.

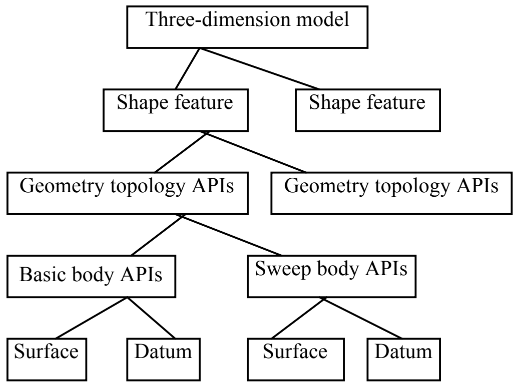

Figure 1. three-dimension model decomposition

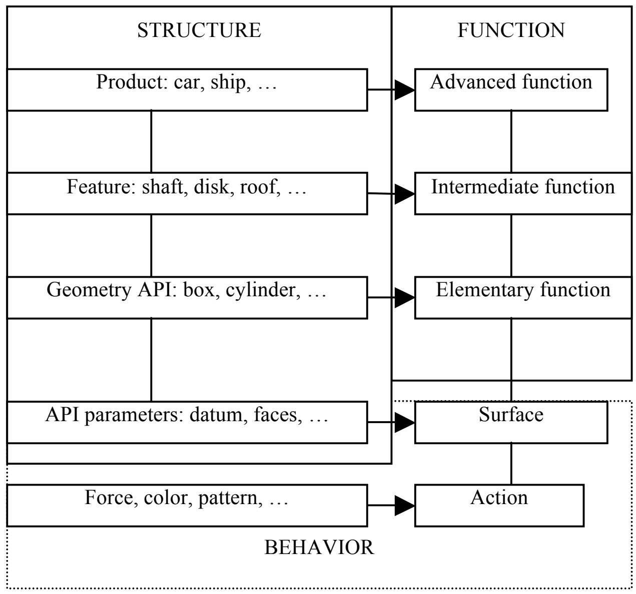

Figure 2. ontology based on FBS

B. Design Ontology based on FBS

Ontology is represented by classes, attributes and instances, and it is a directed graph structure, nodes for the concepts, arcs for the relationships between them. The conceptual design knowledge system expressed with the ontology based on FBS is shown in figure 2.

The product ontology is about the concept of product categories, their structures need to be broken into parts or features to be described one by one, and their functions are also the highest level of abstraction. The product ontology has at least three types of attributes: has-function, shape, whole-part. Has-function is data type attribute corresponding to a word in the function vocabulary; shape has multiple sub-attributes such as pictures, performance parameters, maintenance manuals; whole-part indicates feature instances as the compositions of a product structure.

Features are geometry constructions independently completing certain functions, thus they at least have has-function attributes and shape attributes.

Geometry APIs as mathematical expression and as micros are the basic geometric particles to produce surfaces with actions. They are the surface-behavior attribute values of the principles mapping to functions.

The structure instances on the left of the above figure top-down present a whole-part relationship, and the upper level involves whole-part attributes. The functions on the right layers expressed by words state the purpose of the corresponding structure, and they are also a whole-part relationship from top to bottom.

Besides the above attributes, the structure in every level has topology (TOPO) attribute. Structure individuals are the instances of geometry structure classes, and some design semantics are expressed by TOPO attribute such as circular array.

C. Geometry API Ontology

Geometry APIs and surface-behavior are the basis of the above FBS ontology. Designers complete product modeling by clicking on the menus in the design process, these menus as the macro of methods are in fact geometry body APIs and geometry topology operation APIs, and each API has the semantics about product and design process, shown in table 1.

APIs (API blocks) contain three kinds of attributes:

1)Shape attribute such as coordinate, datum, boundary curve, center, etc. 2) Surface-behavior attribute: every surface with action is the attribute of API blocks, whose identity contains the name of a surface entity and the sequence number in the API bulletin board, such as planar(#), sphere(#)、cylinder(#). 3) TOPO attribute: body API instances are combined into API blocks through self-replicating, arraying and Boolean operating which reflects the spatial topological relationships, shown in table II.

IV. APPLICATION OF THE DESIGN ONTOLOGY

The design knowledge represented with ontology is stored in the knowledge base which need to increate and operate through the semantic framework including knowledge modeling, storage, retrieval, validation, analysis and reasoning. The design knowledge base is a collection of statements (RDF triples) whose main contents are explicit facts, and the inference engines entail the implicit facts in the semantics and rules by the forward and backward link reasoning. The purpose of establishing design ontology is to obtain the satisfied ontology elements to constitute design plans by querying and reasoning according to the rules and the requirements expressed with OWL triples and SWRL.

TABLE I.
BODY API ENTITIES

Body API	Basic APIs	Box, pyramid, wedge, dome, sphere, cone, torus, poly body
	Sweep APIs	Extrude, revolve, sweep, loft

TABLE II.
TOPO ATTRIBUTES

topology	Modification	Presspull, chamfer, fillet, move, rotate, mirror, array, scale_array, scale, align
	Boolean operation	Union, intersect, subtract
	Euler operation	face_extrude, _move, _offset, _rorate, _taper, _sperate, _shell

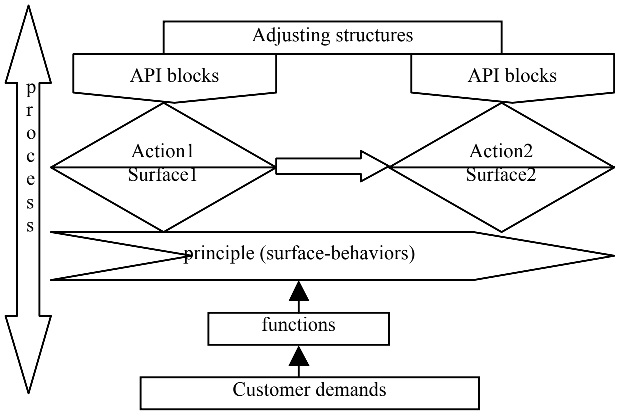

Figure 3. design process based on design ontology

A. function-oriented design

The function design is to find the auxiliary functions based on the core function, the design result is a tree with nodes of function words. Designers can get its ancestor nodes AF and descendant nodes DF through one function concepts or instance.

If a function concept FC_i has instances FI_{i1}, FI_{i2}, … FI_{ij}, …, so designers can get function trees by the following:

Select ?AF ?DF

Where { ?AF whole-part $FC_i(FI_{ij})$

$FC_i(FI_{ij})$ whole-part ?DF} (1)

Or

Whole-part($FC_i(FI_{ij})$)∧part-whole($FC_i(FI_{ij})$)

→?AF ?DF (2)

Similarly structure trees or product structures are finished according to feature instances or API instances.

B. Iterative design from function to structure

The ultimate goal of the product design is to get the product structure. Designers summarize the core functions from the complicated requirements and get the auxiliary functions by machine reasoning with whole-part attributes, and then finish structures from the corresponding behaviors.

Suppose a design task is to design a product P according to a function FC or FI which is converted by customer demands. FT (F_i) as function tree of FC or FI is obtained by (1) or (2), and the mapped behaviors ?B can be selected from many results of (3) by designers.

Principle (FT (F_i)) →?B (3)

The structure ?S(API_k) mapping with ?B is finished by:

Surface (?B) →?S(API_k) (4)

Now, the initial product structure of P and its parameters are designed, next designers adjust the parameters to satisfy performance requirements, shown figure 3.

C. Lightweight network transmission and sharing

Design intent and parametric information of CAD models can be lost when exchanging data by STEP in a distributed environment [22] where heavy geometric data traffic is transferred. Design ontology based on FBS-API can transmit design knowledge such as principles to understand and share, and also the light data traffic is obtained due to transferring API name only.

V. CASE DEMONSTRATION

The design ontology is established in a variety of software integration environment including the compiler tool Java 1.6, the editing tool protégé, the inference engine HermiT 1.3.6, the geometry modeling tools SOLIDWORK and ACIS. The surface-behaviors and API blocks are produced with the help of designers, and other knowledge is automatically obtained.

The design based on ontology is specifically addressed by a gear pump as the case. The design ontology related with gears is shown in figure 4.

The liquid is pressurized and output by a pair of meshing gears in a gear pump, so the meshing gears to complete the core function is the design focus around which other structures complete the auxiliary functions. The gear pair structures comprise the active gear and passive gear with the shafts at the both ends, the longer input shaft of the active gear need to be designed to install the power gear.

"liquid pressure" as the core function links its auxiliary functions with whole-part attribute whose values are the functions of "liquid seal", "power input", "visual appearance", etc. The core function is mapping with the liquid pressure principle with surface-behaviors. The power gear transmits the force on the spline surface <peditsurf(#20), (1,0,0)> into the active gear shaft, and then the force of the gear surface <peditsurf(#300), (-1,0,0)> overcomes the liquid resistance to increase the liquid pressure. The cylinder surface of gear shaft supports the gear by the force <cone(#150), (0,1,0)>, shown in figure 5. All the surface-behaviors are produced by calling API blocks, designers change the attribute values of the APIs to optimize their performances.

VI. FUTURE WORKS

This paper is trying to solve the representing, sharing and reusing the design knowledge through the further analysis and deconstruction of product design FBS models based on geometry APIs and surface-behaviors from the point of view of ontology.

There are still some problems to solve. The conversion from design requirements to functions is needed by means of artificial helps which will produce the inconsistency of knowledge. The structure elements are regulated via APIs, but standards need to guide the further development of the entities on function vocabulary. Especially, the geometry visual and interaction engine need built to facilitate designers to see and check.

The future works include: establishing the unified and standardized constituents of functions; extending the design ontology into product life cycles; unifying API concept from heterogeneous CAD.

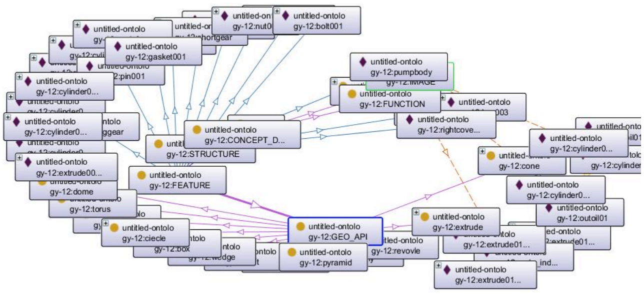

Figure 4. FBS-APIs-based ontology of gear pump

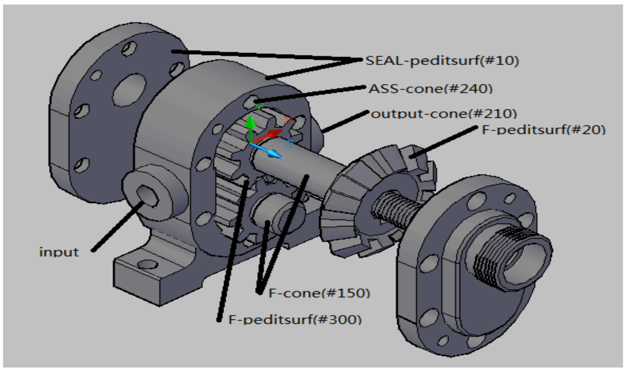

Figure 5. gear-pump design ontology visualization

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