Applying Ontology-based Knowledge Methodology in Product Innovative Collaborative Conceptual Design Framework

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Abstract: In this research, an ontology-based knowledge methodology is utilized in distributed design environment. It is composed of a regular restrictions-based method for expressing the aspired functions, a field-independent method for constructing functional knowledge of given criterion solutions, and a heterogeneous-substance-search method for combining given criterion solutions to reach the aspired functions. This research presents that the capability of function design ontology (FDO) to be inferred can acquire the design intentions by an exposition with a real toy product. Finally, this research proposes a novel framework of information sharing in product innovative design and a design viewer for collaboration in product generation.

1 INTRODUCTION

To develop a sturdy function-oriented model needs a comprehension of component geometry and its substantial outcomes. The morphological characteristics are also importance except the geometric properties. They are results of the principles substantial processes and of the design intents. However, present solid modeling software offer incomplete product descriptions and are not able to perform in the light of the semantic content of the models (Zhang, 2010). Furthermore, the semantic web sustains combined and similar entry to services and message sources as well as to intelligent utilizations by the definite expression of the semantics involved in an ontology. While designer turns into increasingly knowledge-intensive and collaborative, a concurrent crucial for computational platforms to enable conceptual product generation, by effectively supporting the regular expression, recovery, and reuse of product information will be achieved. (Kissel et al., 2012)

This research addresses a collaborative knowledge-based product innovative conceptual design mode that function design ontology (FDO) performs in a regular, definite description of a shared conceptualization of product design modeling. The FDO, in which is derived from AsD ontology (Kim et al., 2006), makes design knowledge accurate and machine-interpretable. In this research, implicit design constraints (including criterion solutions) are definitely expressed using Semantic Web Rule Language (SWRL) and Web Ontology Language (OWL). A meta-pattern, function interconnection pattern (FIP), which was initially constructed to acquire the relations in function engineering, is promoted utilizing the ontology techniques to meet the requirements in collaborative engineering. The implicit conditions of function engineering relations are expressed by utilizing SWRL norms and OWL triads. The FDO also acquires a design rationale, including the function intention, assembly, and spacial relations. This work generates an information sharing circumstance in innovative conceptual design that can inquire FDO messages selectively.

2 RELATED WORKS

Existing computer-aided conceptual design systems can be classified as reuse-oriented systems and creation-oriented systems. The former often aim at modeling the product knowledge of a total engineering system for guiding subsequent design of similar systems. For instances, the FBS modeler employs the Function-Behavior-State approach to model the function-related knowledge of existing criterion solutions for reuse (Cabrera et al., 2009). Based on an existing functional taxonomy, several studies have developed component taxonomy for archiving, searching and reusing component

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knowledge (Joshi and Pathak, 2011). The latter generates a criterion solution for a desired function through recalling basic components from its component library and synthesizing them together for a desired function. Based on the fact that systems in different disciplines can be represented with similar graphs on the mathematical meta-level, the infused design approach employs multiple graph representations to identify suitable problem-solving methods from related disciplines for human designers. However, it cannot integrate criterion solutions in multiple disciplines into one system. The above literature analysis discloses there are still no suitable computer-aided conceptual design systems for fulfilling innovative conceptual design in a collaborative environment.

Observing the product from the constructional point of view gives a product break down structure (product, assembly, subassembly, component, and feature) each of which requires be designing and therefore calling as product design units (PDEs). A PDE at component building level is a reusable design information unit representing a potential solution means for a function requirement. Rehman and Yan (2003) proposed a generic function to PDE mapping process model for supporting decision making in the conceptual design stage. Baxter et al. (2007) categorized existing work in which the design process has a relationship to design information management or design reuse mainly into: (i) Design process with the information management at its core; (ii) Integrating design rationale process; (iii) Design methodology as design process description or management method; (iv) Design information capture and representation through design processes. Panchal et al. (2006) developed an approach for the integrated design of materials, products, and design processes which was based on the use of reusable interaction patterns to model design processes, and the consideration of design process decisions using the value of information metrics. It was shown that the integrated design of materials and products can be carried out more efficiently by considering the design of design processes. However, their style still has implicit restraints and relations that cannot be analyzed by a calculator in a semantic web circumstance. This research will develop the FDO style using ontology technology. The FDO will definitely express conceptual design restraints and the calculator will can reason the surplus implicit ones. Meanwhile, the function interconnection pattern (FIP) will involve the motion characteristics in product innovative conceptual design except the static assemble conditions.

3 SYSTEMATIC REPRESENATION AND SYNTHESIS APPROACH

A HeOS-based (Heterogeneous Object Search) synthesis method is generated in order to accomplish ICD in collaborative environment. The agent concept (Russel and Norvig, 2009) is utilized to illustrate the HeOS-based synthesis method. It is supposed that there is a SCD (Smart Conceptual Design) agent that involved all criterion solutions in its knowledge base. For SCD agent, the given criterion solutions can be considered as its behaviour devices for converting import flows, the import flow(s) derived from an aspired function can be its original condition, and its export flow can be the target situation. This agent can sense its condition automatically, and can choose proper criterion solutions from its knowledge base to perform it, until the target conditions is achieved. The condition of SCD agent consists of the flows that SCD agent can detect. Besides, each flow is also expressed with a name of flow, along with a group of attribute-values. Following the attribute restraints on the import flow(s), SCD agent can create original conditional flow(s) by integrating whole probable values of each attribute completely, and place them into its condition. After a given criterion solution is specified to perform a conditional flow, some export flows can then be created that are also place into the condition for farther design synthesis.

After a qualified criterion solution has been recognized, SCD agent will then decide how it performs the present conditional flow, where the main attention is what flow(s) the criterion solution will export. The functional knowledge of the criterion solution is utilized to predict the export flow(s). In a state space of heterogeneous substance, what SCD agent should predict originally is the name of the export flow. Based on the import-export flow name pair(s) of a given criterion solution, SCD agent knows the name of the export flow. Then SCD agent has to decide the value scopes of the attributes for the export flow. This procedure includes two portions. One is to decide the value scopes of the attributes in accordance with the attribute-mapping norms of the criterion solution. For instance, when the criterion solution Crank-slider mechanism is utilized to perform an import “Angular_velocity” flow with its attribute *Axial_orientation* set as *Z*, the attribute orientation of the export "Linear_velocity" flow can then be predicted as either *X* or *Y*. Another is to decide the value ranges of the attributes that are not restricted by the attribute-mapping rules, using the attribute constraints of the selected criterion solution on its export flow. Eventually, SCD agent creates all possible export flows, using the value scope determined for each attribute. This can be done by extracting each value decided for each attribute and combining them together in an thorough way. This action process can be shown with an example shown in Figure 1, where the allowable value scopes that SCD agent has determined for the attribute of the export flow are shown in the right side. Based on these allowable values, SCD agent generates two probable export flows by means of a thorough conjucntion process, i.e. "Linear_velocity {*Stability*: variable; *Orientation*: *X*; *Direction*: reciprocating; *Motionstate*: continuous}" and "Linear_velocity {*Stability*: variable; *Orientation*: Y; *Direction*: reciprocating; *Motionstate*: continuous}".

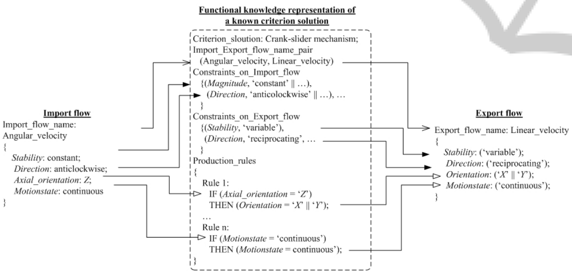

Figure 1: An example of SCD agent's action process.

In order that SCD agent can investigate in collaborative solution environment for discovering the conjunctions of novel and potential criterion solution, the thorough search approach is utilized to generate the automated ICD synthesis algorithm. The process of design synthesis can then be implemented after a designer imports an aspired function with the restraints on the import and export flows. Besides, it is important that a designer takes care of the most potential criterion solution selected for refining farther design after various combinatorial criterion solutions are exported. If SCD agent cannot create a potential criterion solution with the assigned the maximal depth for searching, the designer may add the maximal depth for searching and re-begin the process of design synthesis.

Suppose a designer intends to develop a toy dog that can shake its head and tail after turning on the switch. A solar energy is chosen for driving the toy. Utilizing the proposed method of functional expression, the import flow, i.e. the solar light, can be expressed as "Lighting_energy {*Stability*: constant || variable; *Motionstate*: continuous; *Type*: Hot_light}", while the export flow, i.e. the head and tail-shaking action of the toy, can be expressed as "Angular_velocity {*Stability*: variable; *Axial_orienation*: *X* || *Y*; *Direction*: reciprocating; *Motionstate*: continuous}". To illustrate this example, several criterion solutions are chosen to create the criterion solution knowledge base, which are Crank_slider, Spur_gear_pair, Crank_rocker, Rack_pinion, Transformer, Solar_array, AC_motor, DC_motor, Electrical_inverter, and Light_emitting_diode. Meanwhile, the process of design synthesis is depicted below: (1) SCD agent converts the restraints on the import flow into some detailed circumstance. Consequently, two original environmental flows are generated. (2) SCD agent starts to perceive its circumstance. The first conditional flow perceived is the flow "Lighting_energy {*Stability*: constant; *Motionstate*: continuous; *Type*: Hot_light}". SCD agent then explores the restraints of the given criterion solutions on the import flows to discover qualified criterion solutions. Hence, the criterion solution Solar_array is recognized as a qualified one. (3) SCD agent applies the functional knowledge of the recognized criterion solution to perform the present flow. Based on its name pair of import-export flow, SCD agent finds that the criterion solution will export an "Electrical_current" flow; in the light of the relevant attribute-corresponding norms and the attribute restraints on the export flow, then SCD agent can decide the value scopes of the attributes for this export flow, and then create an export flow, "Electrical_current {*Stability*: constant; *Motionstate*: continuous; *Direction*: positive; *Type*: Direct_current}", which is also place into its condition. Subsequently, SCD agent keeps on detecting its condition until whole conditional flows have been searched. When a flow is detected as unsearched, it will then discover suitable criterion solutions to perform it, and the recently-generated export flows will be increased to its environment. (4) when the search process terminates, SCD agent then searches for the environmental flows that can meet the restraints on the export flow (goal), and get whole relevant flows by a backtracking process, with a effect of some conjunctions of given criterion solutions. For instance, SCD agent will then get the relevant flows and bind the corresponding criterion solutions as a combinatorial criterion solution when the flow "Angular_velocity {Stability: variable;

Motionstate: continuous; *Axial_orientation*: X; *Direction*: Reciproating}". The combinatorial criterion solution is listed "Solar_array → DC_motor → Crank_rocker".

The above design project shows that SCD agent can create combinatorial criterion solutions for a aspired function by integrating given criterion solutions from diverse disciplines into a collaborative environment. For instance, when the maximal depth for searching is set as four, a combinatorial criterion solution, "Solar_array → Electrical_inverter → AC_motor → Crank_rocker", can be created, which is included criterion solutions from diverse fields, e.g. mechanical engineering, electrical engineering, electronic engineering, etc. Furthermore, the SCD agent cannot only determine whether various criterion solutions meet each other in flow names, but also can verify if they are congenial regarding the elaborated properties.

4 FRAMEWORK OF INNOVATIVE CONCEPTUAL DESIGN

4.1 Function Relation Model

To fulfill the desired functions, the mechanism design portion also has to be involved in the innovative conceptual design system except the above mentioned approaches. Thus, a FIP is generated in this research. It is a meta-pattern with XML format, developed by utilization of the FDO style. All geometric elements in the FIP are connected to a relevant solid model, namely, the output of the style is an XML file deriving from geometric elements in a CAD model. By utilization of FDO style, a designer can assign linking modes, linking conditions, and spacial relations between components in a CAD circumstance. Figure 2 illustrates a Unified Modeling Language for showing a FIP static structure. Function has "part_of" relations with the two features (assembly and component), and component has "part_of" relations with the feature form. The feature assembly is crucial factor for realizing the function intent. It involves the characteristics below: coupler, matching, degree of freedom, and material. The FDO style that acquires motion, assembly, and linking relations of a product, is included several aspects: extraction of feature matching, description of spacial relation, extraction and generation of feature coupler, generation of feature assembly as well as relation extraction of function engineering.

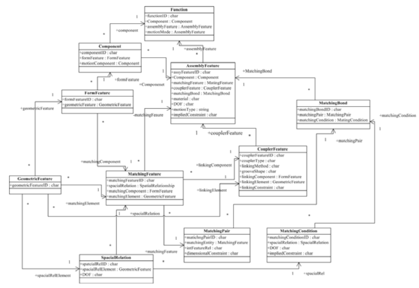

Figure 2: The diagram of function interconnection pattern – UML format.

4.2 Ontology-based Function Design

In this framework of ontology-based function, product properties, assembly, function, and linking procedures are generated in an ontology. Different collaborative designers can entry the function messages by utilizing a semantic inquiry while applying collaborative design tools (called eCol-tools). The FDO has been generated based on a FIP, which was depicted in Section 4.1; the ontology-based FIP acts as a meta-pattern that provides a connection between CAD models and function relations. Besides, the FDO ontology also offers facts by utilization of a reasoning module.

In innovative conceptual design, OWL and SWRL are utilized for establishing relationships. This study indicates that SWRL principles can be inferred to supply semantic inquiries and information requirements in a collaborative ICD circumstance. To develop the FDO and principles, Protégé SWRL editor is applied for this research. There are three types of relations, spacial relations, and linking relations expressed in OWL and SWRL. First of all, the relations between a feature form and a feature component are expressed the "Inhere". The **Inhere** relations infer two constraints. The inferred constraints can be transformed to two alleged conditions.

Meanwhile, the relations among form features are expressed the "Inter-Conjunction". The constraint (Rc_{uv}) means the relation between two form features in the hierarchy of form feature. The generated SWRL rules are used to add new facts and utilized in a fact-adding mode only in this research.

Finally, the relations between form features that inhere to different components are defined the "linking". The implied constraints are represented in SWRL rules.

The designer's initial intention forced on function design can be investigated through a definite linking manner and the planned degree of freedom. For instance, if designers intend to perpetually bind two components to move simultaneously, they specify spacial relations to fasten them. A designer concerns a fastened coupler and assigns a screwing utilization for a linking manner, then the degree of freedom consistent with the screwing utilization can be reasoned by applying the ontology inferring ability, and utilized to check if this screwing utilization will meet the designer's intention on the function. The SWRL principles to express spacial relations, degree of freedom and inference instances are depicted (Kim et al., 2006): (i) aligned spacial relation: Two components that aligned between collinear lines along the direction *y*, have degree of freedom of {*lin_y* :: *rot_y*}. (ii) against spacial relation: Two components that have against spacial relation between planar surface along the direction *x*, have degree of freedom of {*plan_x* :: *rot_x*} - in other words, plane degree of freedom along *x*-direction of the coordinate of the instance component and rotational degree of freedom within its own coordinate system (*x*-direction). (iii) decrease in degree of freedom: When multiple spacial relations are assigned, the result of interaction of degree of freedom should be decided to realize the resultant degree of freedom. (iv) bolt with nut or rivet: If a component is joined by more than on bolt with nut or rivet, the component has restricted degree of freedom.

5 THE FRAMEWORK OF DESIGN INFORMATION SHARING

A novel framework of design information sharing and design viewer generated by utilizing the standard widget toolkit (SWT), Java, and the Jena ontology application program interface. The design viewer delivers just an essential group of design information in a collaborative environment and hence it conquers the obstructions of present conceptual design systems that designers have to find either with finite sustains of system or manually to find appropriate design information. As an instance, let us consider the scenario that tail mechanism of toy dog is being concurrently generated by multiple collaborators in distributed environment.

In the distributed framework, the function ontology is corresponded to the FIP, and the FIP is definitely connected to a consistent solid model. Figure 3 shows a structure for the information sharing in conceptual design. First of all, product relationships, i.e. function, are acquired from the function design models that are created by different CAD tools, and the consistent FIPs are created. This FDO module executes the selection and FIP creation as the FDO generator. The FIP is corresponded to the consistent CAD model. The FDO is created by utilizing an ontology tool, e.g. Protégé, and the OFM generator creates an ontology-based function model (OFM) that an ontological expression of FIP, and executes the corresponding with the FIP messages. The OFM generator converts the normalized contents in FIP to OFM, when reasoning the pre-constructed ontology. OFM strictly follows the ontological rules in spite of the FIP created from different CAD systems may be heterogeneous. The inferring unit performs the rules in FDO, and puts recently detected facts to the OFM base. The FDO viewer treats embedded inquiries and customized inquiries by utilizing a query unit based on the OFM. The unit spread the outcomes through the ontology and then transmits the outcomes to the conceptual design browsers.

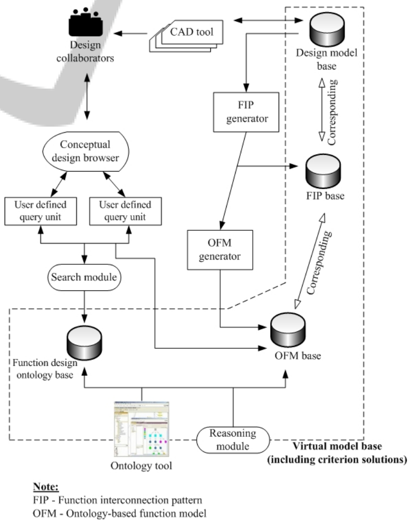

Figure 3: The framework of conceptual design information sharing.

6 IMPLEMENTATION OF SYSTEM

In this framework, the elements in the ontology are persistently connected to a corresponding solid model by FIP, which is format and application independent. In this way, the designers do not need to know a specific CAD format, and loss of information is relatively low since design information is represented explicitly in the FRM. Figure 4 shows the interface of conceptual design browser, designers can search for product models that contain relevant design information by using the interface. There are several views of the product information provided on the browser: a hierarchical view of the ontology classes, a product geometry view (assemble/exploding condition), and view of a model data structure and XML structure. Through browsing the ranking system, a designer can decide that classes are definitely expressed in the model and their sub-class relations. The XML view offers the designer the chance to examine the structure in that the model will be delivered from one system to another. Meanwhile, the viewer of conceptual design explores for relative elements by utilizing keyword that investigates class structure and file name of the relevant ontology model. The relevant model comes back files that involve the particular design messages if the search rules are met. Besides, other search rules are also shown to make supplementary searches on similar items for designer. For instance, if a designer searches for linkage assembly that involves screwing information displayed in Figure 4, other search rules such as riveting, welding, or adhesive bonding may be returned by utilizing the ontology model because they are also joining methods, which is a result of a semantic query.

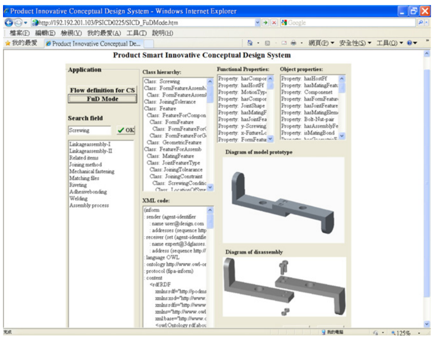

Figure 4: Screen snapshot of SICD system – FDO viewing browser.

7 CONCLUSIONS

In this research, the proposed approach for ICD system paves a path for designers to integrate criterion solutions from various disciplines into a collaborative framework for fulfilling a desired function. It is mainly composed of a formal approach for representing a desired function, a domain-independent approach for representing functional knowledge of known criterion solutions, and a HeOS-based synthesis approach for automated ICD system in collaborative environment. Furthermore, the author has also proposed a collaborative ICD structure sustained by an ontology-based knowledge methodology. The generation of a FDO mentions the requirement that product design has for high-level semantic modeling. High-level semantics and a normailization of function notions as well as relationships among those concepts give the calculator the capability to infer messages for the instances of particular function model. In this research, function knowledge has been categorized into a ranking system of function concepts. They inserted in conceptual design have been defined utilizing particular names and hence have generated a normal vocabulary to depict functions. This is essential for concerted function design that in various disciplines symbolically include. This research obtains most benefits of OWL and SWRL techniques to express complex relationships that are spread among form properties and components. Because the restrictions have been normalized, they can be explained and kept in a normal way in the collaboration period. The FDO and viewer can be applied in different activities regarding the collaboration in product design modeling.

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