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Methods for Supplier Library Construction and Parts Similarity Measurement in Web-Based Parts Library Platform

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Abstract

As production becomes more specialized, product data sharing and exchange between specialized parts manufacturers and complete machine manufacturers have become an urgent demand. In this study, we first present a meta model of a supplier library based on PLIB ontology and ISO13584 and then propose a graph-structured semantic model (named as form feature dependency semantic (FFDS) graph in this paper) to formally represent the structure of parts (form features and their topological relationships). Moreover, we propose a new method for part similarity measurement using FFDS graph, as well as discuss the technical details of this method. The proposed method ensures the success of the structure feature-based retrieval in part search procedure. A case study was presented to demonstrate the proposed method.

Key words

Supplier library, web-based parts library, similarity measurement, form feature

1. Introduction

Products are often made of parts. When the parts in a product are defined independently of the product itself, e.g. by a part supplier, the information about them is independent of any product where they may be used [1]. As production grows more specialized, collaborative and globalized, product data sharing and exchanging between specialized parts manufacturers and complete machine manufacturers have become an impending demand.

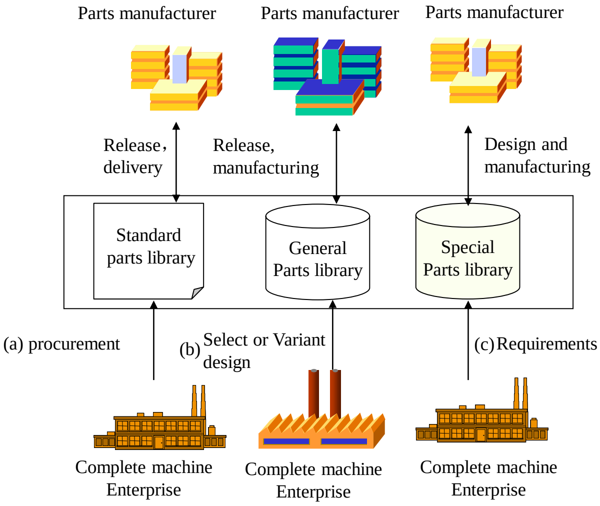


Fig. 1. The collaborative relationship between parts manufacturer and complete machine manufacturer

Web-based parts library (or E-catalogue), a library which either contains or may generate information about a set of parts, is designed as a public platform that the part manufacturers can upload their electronic catalogs and 3D CAD models and then machine manufacturers could download their needed 3D CAD models in the stage of product design[1-3].According to the investigation[4], 85% of those products are subsequently purchased when the part manufacturers' 3D product models are selected and downloaded into their customer's designs.Web-based parts library platform(or E-catalogue) has been proved an important tool and bridge in Collaborative Design, Concurrent Engineering and Electrical Commerce[5]. The supplier libraries (set of data, and possibly of programs, that describes in the standard format defined in this International Standard, a set of parts and/or a set of representations of parts[1]) are the main providers or the main sources of one web-based parts library platform(Fig.1) (From Electrical Commerce(EC) viewpoint, the supplier library is supplier's E-catalogue. In this paper, we call it as S_PLIB).

The supplier library differs from the traditional parts library, which is only used in enterprises. The end users or customers of web-based parts library platform include designers of complete machine manufacturers, ordinary CAD users, and the purchasing specialists of complete machine enterprises. According to ISO13584, the supplier library is not a simple accumulation of part CAD models (the Parts Library, which aims to develop a computer-interpretable representation of parts library data to enable a full digital information exchange between component suppliers and users, was granted the ISO level in 1990). In parts library, a part is not only a set of attribute values but also an understandable abstraction. These abstractions are defined not only for computer sensible but also for parts library end users to allow them to consult the library data and select parts and pertinent part representations [1].

According to the International Standard of Parts Library [1,6], the content of a supplier library should include two kinds of classes: general model class (which includes generic family of parts and simple family of parts) and functional model class (Fig.2). The general model class corresponds to the specification of the parts family and defines the parts and describes their intrinsic properties. The functional model class provides the 3D/2D model of their parts and the related technical documents.

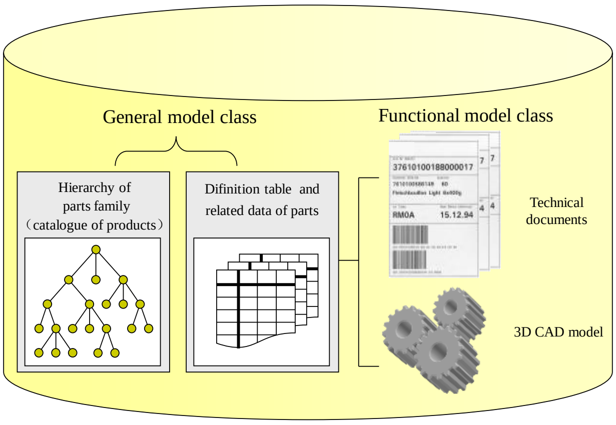


Fig. 2. Required content of a supplier library

The ISO 13584 has specified the representation of a part family and the content of a supplier library, but it does not provide an executable method to guide the parts supplier in constructing their supplier library. Our current work is motivated by the need to help suppliers build their interoperable and integratable parts library that allows exchange of data between organizations, facilitating generation of information about products that contain such parts.

We propose an information model of a supplier library based on PLIB ontology (A PLIB ontology is modelled according to the PLIB (meta) dictionary model, that is the ISO13584-42) and then proposed a new method and graph-structured semantic model (named as form feature dependency semantic (FFDS) graph in this paper) to formally represent the structure of part (form features and their topological relationships); moreover, a similarity measurement based on this structured semantic graph model and its technical details are addressed. The proposed method ensures the success of structure feature-based retrieval in part search procedure. We demonstrated the feasibility of the proposed method through a case study.

The remainder of this paper is organized as follows. A meta model of supplier library based on PLIB ontology and ISO13584 is proposed in Section 2; additionally, the FFDS graph is introduced in this section. In Section 3, a part similarity measurement based on FFDS graph is discussed in detail and the feasibility of the proposed method is demonstrated through a case study. Section 4 presents the objectives of future works.

2. Meta model of supplier library

In supplier library, parts are grouped into part families that are represented by classes. This set of classes is organized according to a simple hierarchy of classes .The upper classes are called generic family of parts, and each class is precisely described (textually with technical drawings and formally by class relationships). The leaf of the hierarchical tree is called a simple family of parts, and each class is associated with a set of technical properties, which are described both textually and formally (domain of values and possible measurement unit).

An information model of the proposed supplier library is constructed based on the standard ISO13584 and PLIB ontology ([7]. This information model of the supplier library consists of two levels: ontology level (semantic level) and instance level.

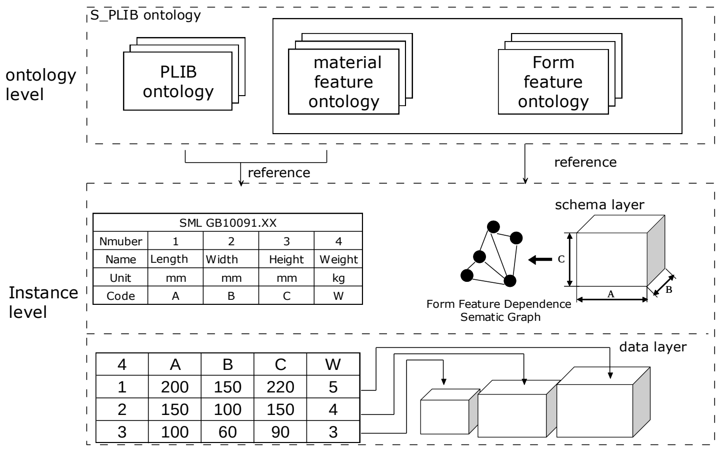


Fig. 3. Meta model of supplier library based on PLIB ontology

2.1 Ontology level of supplier library-S_PLIB ontology

S_PLIB ontology consists of PLIB ontology [7], material feature ontology, and form feature ontology. Material feature ontology and form feature ontology are the complements of PLIB ontology. These three kinds of ontology describe most of the facets of parts and thus can facilitate part retrieval and reuse in web-based parts library platform.

The description and scope of S_PLIB is limited to a supplier's products. According to the International Standard ISO13584, every supplier can build his own local ontology or refer to other organization's ontology, such as some PLIB ontologies (e.g., ISO13584-511, which is issued by International Organization) to build his own local ontology. However, some rules must be followed [2]:

Each local ontology class in local ontology is possibly based on the classes defined in shared ontology (standard ontology, e.g., IEC61360 and ISO13584-511);

Only class(es) or properties that do(es) not exist in shared ontology can be defined in a local ontology (That is, in the present case, library supplier can extend the semantic dictionary;

A part ontology model can be built based on the ontology defined at the ontology level. In the ontology level, part model is based on OWL.

2.2 Instance level of the supplier library

Based on the characteristics of database, the instance level is divided into schema layer and data layer. This paper mainly discusses the schema layer.

From the OWL ontology, the schema layer can be built through the map from OWL ontology to relationship database [8,9]. Figure 4 shows the framework which how to convert the owl ontology into relational database schema. The input source is the owl file from the S_PLIB ontology. OWL files are mapped into data structure based on the map rules [9].

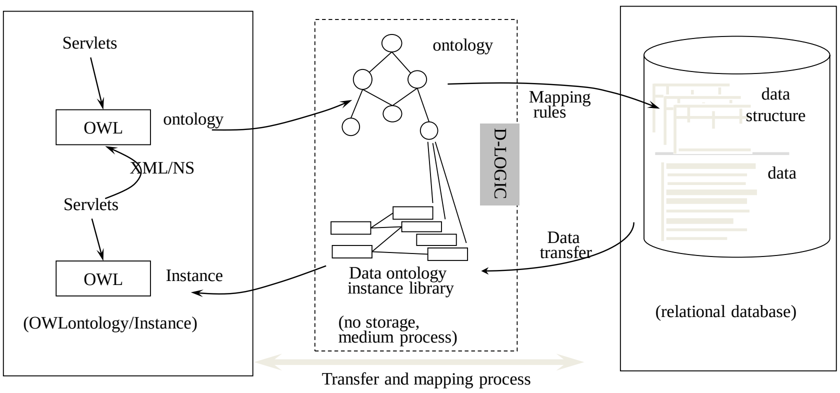


Fig.4. The conversion framework that from OWL ontology to relational database schema from OWL to databased Schema

2.2.1 Tabular Layouts of Article Characteristics (Sach-Merkleisten in German or SML)

The SML describes the standardization and regularization of a product [10]. In the supplier library, the SML corresponds to the definition table in Fig. 2. Article characteristics can be extracted from S_PLIB ontology, and the SML can be seen as a subset of the schema of parts library's database schema. In supplier library, a simple family of parts can be expressed and controlled by SML and by a CAD model (called master model [11]

As shown in Figure 5, the instance of parts can be quickly formed in CAD system by building the map relationship between the table columns of SML and the parameter list in the parametric CAD system. This method is called SML+master model technology [11].

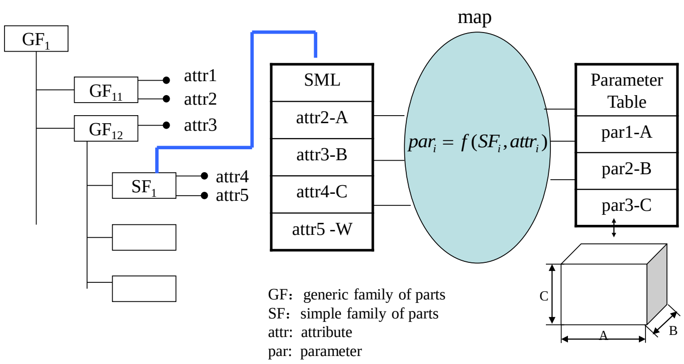


Fig. 5 Mapping relationship between S_PLIB ontology, SML, and parameter table of parts function feature (SML- tabular layouts of article characteristics)

2.2.2 FFDS graph

With the development of 3D modeling technology and web technology, many web-based 3D model libraries have become available in the Internet. Parts library is one kind of such web-based 3D model library. Considering that the recall ratio and precision ratio of traditional text-based 3D model retrieval technology cannot meet user's demand [12], some researchers have proposed a content-based 3D model retrieval technology [13, 14]. This technology displayed enhanced recall ratio and precision ratio. However, some disadvantages are noted, such as low efficiency and considerable cost of computation. Nevertheless, the 3D model is used to compare with the models in content-based 3D model retrieval method. Feature-based modeling technology has been adopted by most mainstream CAD systems. Various feature-based CAD/CAM systems (e.g., NX and Pro/E) are available in the market [15]. Moreover, feature-based design has been popularly used in mechanical design. Form feature always reflect a designer's intention to some extent.

Thus, this paper proposes an FFDS graph, which uses a semantic concept graph to describe the topological relationship of form features. An FFDS graph can be seen as a formal model of part structure.

The topological relationships of features can be divided into four types: detachment relation, adjacency relation, intersection relation, and containment relation (Fig.6). The detachment relation indicates that two features have no common intersecting spaces (or containment relation). The adjacency relation indicates that two features have common plane, and the total space is the sum of the individual spaces of these two features; intersection and containment relations indicate that one feature is located partly or wholly within another feature, and the total feature space is the difference of the respective spaces of the two features.

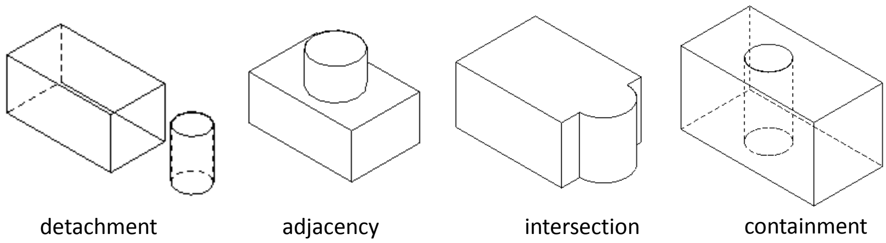


Fig. 6. Topological relationship between form features

The concept FFDS graph is defined in 2-1 according the topological relationship between features.

Definition 2-1 FFDS graph. An FFDS graph mainly describes the topological relationship of part features. Moreover, an FFDS graph can be described as $G = (V, E)$, where V is the finite set of features and represented as $V = (f_1, \ldots, f_n)$; the subscript describes the modeling history. The node is 2-tuple set $\{f_i, A_{f_i}\}$, A_{f_i} denotes that feature f_i is an attribute set, as well as a finite set. The node can be annotated semantically based on form feature ontology, which is defined in S_PLIB's ontology level. E is the finite set of edges in FFDS graph, and the edge in FFDS graph describes the interrelationship of the features; detach relationship indicates that no link(edge) exists between nodes. Based on this topological relationship between features, the set E can be described as

$$E = E_1 \cup E_2 = \{(f_i, f_j)_{i=0..n, j=0..n,\ i \neq j}\} \cup \{< f_p, f_q >_{p=1..n, q=1..n, p \neq q}, vol(f_q) \subset vol(f_p)\} \quad (1)$$

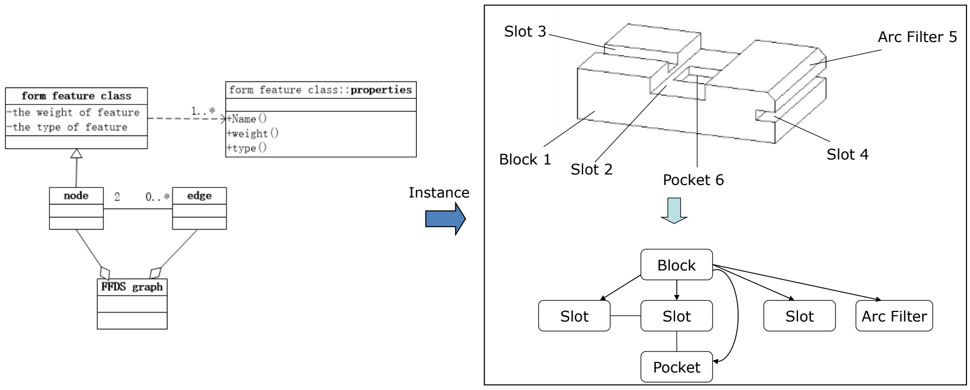


Fig. 7. UML description of FFDS graph and a sample of FFDS graph of a part

In parts library, each simple family of parts corresponds to an FFDS graph or the interrelationship of features in each simple family of parts can be described by an FFDS graph; thus, the structural similarity of parts can be evaluated by an FFDS graph. The similarity algorithm is discussed in Section 3.

An FFDS graph can be constructed via two methods: one is the feature-based abstraction method and the other is the modeling history tree-based method. Currently, the modeling feature can be abstracted from a CAD model through a CAD system’s API. Given that a modeling feature cannot reflect the intention of an engineer’s design, to facilitate knowledge reuse and concurrent design, the modeling feature should be transferred into a design feature or manufacturing feature, which explicitly shows the designer’s intention. We proposed that the concepts to be used in annotating the features should be the leaf node in the form feature ontology so that the leaf node can be instantiated.

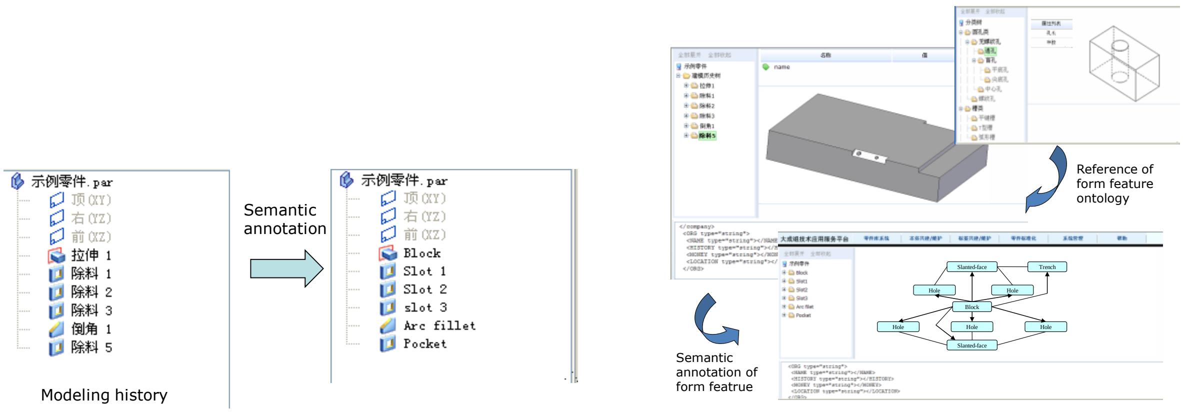


Fig. 8. Sematic annotation of form feature

3. Similarity measurement between simple family of parts

3.1 Overview

As previously illustrated, the parts in a supplier library are grouped as parts family, and each simple family of parts can correspond to a master CAD model in CAD platform; moreover, each master CAD model can construct one and only one FFDS graph. Ma [16]proposed a relevance degree method to narrow down the search space and increase retrieval efficiency in parts library. This method aims to calculate the relevance degree of attributes set between two part families. In the web-based parts library platform, parts resources are provided by different suppliers, and a condition similar to that illustrated in Figure 9 will appear: these parts bear similar part name and display nearly the same function and set of article characteristics, but they exhibit different structures. To deal with such condition and help designers identify the "right" part, we investigated a part similarity measurement method based on the FFDS graph. This method could narrow down the search space, and because FFDS graph is a semantic concept description model of part structure, this method can be seen as the intermediate method between text-based 3D model retrieval method and content-based retrieval method.

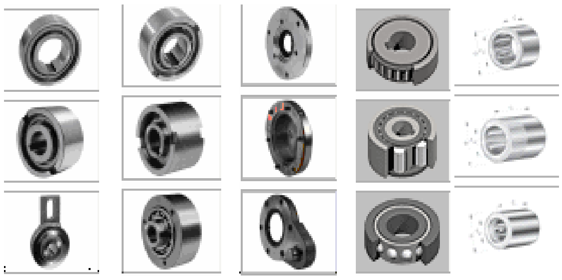


Fig. 9. Example of parts with similar name but with different form features
(source: Traceparts)

Only the type of the form features and relevance state of these form features obviously form one-to-one pairs between two simple families of parts; thus, two simple families of parts (master CAD model) can be considered as similar or identical. For this reason, two factors, namely, the type of form feature (node) and the topological relationship of these form features (edge), should be considered when measuring the similarity of two simple families of parts.

3.2 Introduction of the algorithm

Our part similarity evaluation process is as follows:

(1) A CAD model that corresponds to one simple family of parts is built. The form features and the relationship between these form features can be extracted from the CAD model. An FFDS graph that corresponds to this simple family of parts can then be constructed.

Suppose the FFDS graph of the simple family of parts A is denoted by $G_A = \{V^A, E^A\}$, where $V^A = \{f_i^A\}_{i=1...n}$, n is the number of form feature in parts A, which is denoted as $N(V^A)$, and the FFDS graph of simple family of parts B is denoted by $G_B = \{V^B, E^B\}$, where $V^B = \{f_i^B\}_{i=1...m}$. n is the number of form feature in parts A, which is by denoted as $N(V^B)$. Suppose G_A is smaller than G_B (the total number of nodes in G_A is lower than that in G_B, that is $n < m$); $\omega(f_i)$ is the weight of node in FFDS graph, and $w(e_i)$ is the weight of the edge in FFDS graph.

(2) Similarity measurement of parts: when measuring the similarity of two parts, two factors should be taken into account, namely, the type of feature and topological relationship between form features. Refer to the research on reference [17], we proposed a similarity measure algorithm which is based on FFDS graph.

First, we define the sub graph and map between two FFDS graphs.

Definition 3-1 In an FFDS graph, $G = (V, E)$; the node f_i ($f_i \in V$)and all the edges which links to node f_i will form a trivial graph $G(f_i)$. In our method, we define this trivial graph as sub-graph of FFDS graph.

Definition 3-2 The map from graph G_A to graph G_B is denoted by $\rho: G_A \to G_B$, if and only if :

(a)$\forall f_i^A \in V^A, \exists f_i^B \in V^B$, one form feature f_i^A in G_A corresponds to only one form feature f_i^B in G_B and denoted as $\rho(f_i^A) = f_i^B$. If $\forall f_i^A, f_j^A \in V^A, f_i^A \neq f_j^A$, $\rho(f_i^A) \neq \emptyset, \rho(f_j^A) \neq \emptyset$ then $\rho(f_i^A) \neq \rho(f_j^A)$.

(b) $\forall e^A = (f_i^A, f_j^A) \in E^A$, if $\rho(f_i^A) \neq \emptyset, \rho(f_j^A) \neq \emptyset$ and $e^B \in E^B$, then $\rho(e^A) = e^B$(indicating that e^A corresponds to e^B); otherwise, $\rho(e^A) = \emptyset$ (indicating that e^A does not correspond to any edge in G_B)

Definition 3-3 The map from graph G_A to graph G_B is denoted by $\rho: G_A \rightarrow G_B$, and $f_i^A, f_j^A \in V^A$, $f_i^B, f_j^B \in V^B$, $e^A \in E^A$, $e^B \in E^B$

(a) $S_\rho(f_i^A, f_i^B)$ is defined as the degree of similarity between nodes f_i^A and f_i^B on map ρ. When $\rho(f_i^A) = f_i^B$, $S_\rho(f_i^A, f_i^B) = 1$, and $S_\rho(f_i^A, \emptyset) = 0$, $S_\rho(\emptyset, f_i^B) = 0$. If not, the degree of similarity should be measured according to the algorithm for feature similarity measurement (similarity of features in distance- and attribute-based methods, which are introduced below).

(b) $S_\rho(e^A, e^B)$ is defined as the degree of similarity between edges e^A and e^B on map ρ.

if $\rho(f_i^A) = f_i^B \wedge \rho(f_j^B) = f_j^B, < f_i^A, f_j^A > = < \rho(f_i^A), \rho(f_j^A) >$, then $S_\rho(e^A, e^B) = 1$

if $\rho(f_i^A) = f_i^B \wedge \rho(f_j^B) = f_j^B, < f_i^A, f_j^A > \neq < \rho(f_i^A), \rho(f_j^A) >$, then $S_\rho(e^A, e^B) = 0.5$

if $\rho(f_i^A) \neq f_i^B \vee \rho(f_j^B) \neq f_j^B$, then $S_\rho(e^A, e^B) = 0$ and $S_\rho(e^A, \emptyset) = 0$, $S_\rho(\emptyset, e^B) = 0$

Definition 3-4 The map from graph G_A to graph G_B is denoted by $\rho: G_A \rightarrow G_B$, $S_\rho(G_A, G_B)$ is defined as the degree of similarity between graph G_A and G_B on map ρ and

$$S_\rho(G_A, G_B) = \frac{F_f + F_e}{M_f + M_e}$$

(2)

where

$$F_f = \sum_{f_i^A \in V^A} \frac{w(f_i^A) + w(\rho(f_i^A))}{2} S_\rho(f_i^A, \rho(f_i^A))$$

(3)

$$F_e = \sum_{f_i^A \in V^A} \frac{w(e^A) + w(\rho(e^A))}{2} S_\rho(e^A, \rho(e^A))$$

(4)

$$M_f = \max\left(\sum_{f_i^A \in V^A} w(f_i^A), \sum_{f_i^B \in V^B} w(f_i^B)\right)$$

(5)

$$M_e = \max\left(\sum_{e^A \in E^A} w(e^A), \sum_{e^B \in E^B} w(e^B)\right)$$

(6)

Equations (3), (4), (5), and (6) show that $M_f + M_e$ is the maximum value of $F_f + F_e$

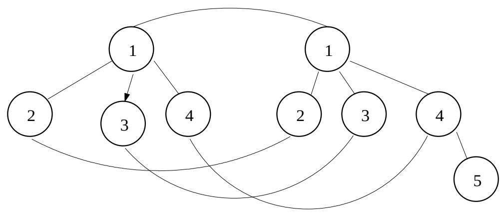


Fig.10. Example of similarity measurement between two FFDS graphs

Figure 10 shows that the weight of each node and edge in FFDS graph is set as 1. One-to-one pairs (map from graph A to graph B) of nodes and edge were built. The nodes of graphs A and B were numbered serially, and node with similar number in graphs A and B indicates that the form features are identical. The similarity of the two graphs in the maps in Figure 9 can be calculated according the above definitions:

$$S_\rho = \frac{4[\frac{1+1}{2}\times 1] + 2[\frac{1+1}{2}\times 1] + [\frac{1+1}{2}\times 0.5]}{5+4} = 0.72$$

According the definition of FFDS graph above, the form feature can be annotated semantically based on the form feature ontology and then by using the semantic concept to express the form feature; thus, the calculation of similarity measurement of form feature is converted into the calculation of concept’s semantic similarity. In the previous decade, researchers have proposed a number of methods to measure the semantic similarity between concepts; these similarity metrics methods can be categorized into dictionary-, corpus-, distance-, and information theory-based methods [18]. Liu proposed that a feature ontology is structured as a hierarchical tree with “is a” or “is a kind of” relationships [19]; thus, the semantic distance-based method can be used to compare the degree of similarity between two features. In addition, each form feature can be seen as an entity class, which is described by a set of attributes (In parts library, these attributes are defined as article characteristics); obviously, the heavier the multiplicity of these two sets of attributes, the more similar two features will be. In this study, two methods are proposed to calculate the degree of similarity between features.

(a) Distance-based similarity between features. In FFDS graph, form feature is associated with semantic concept in feature ontology. Li presented that the similarity between concepts not only should consider the distance (the shortest path from one concept to another) between concepts but should also account the depth of each concept in the hierarchical tree[20]. Overall, the degree of similarity between two form features can be calculated by Equation (7).

$$S_p(f_i^A, f_j^B) = \begin{cases} \dfrac{h}{Dis(f_i^A, f_j^B) + Maxl} & f_i^A \neq f_j^B \\ 1 & f_i^A = f_j^B \end{cases} \quad (7)$$

where

$Dis(f_i^A, f_j^B)$ denotes the shortest path from f_i^A to f_j^B.

h is the depth of the node of intersection of f_i^A and f_j^B (the common parent node of f_i^A and f_j^B) in the hierarchical tree.

$Maxl$ is the maximum depth in the hierarchical tree.

(b) Attribute-based similarity between features. The distance-based semantic similarity measure is closely decided by the ontology's hierarchy levels. Moreover, great variation exists between the level of detail and logic of different ontology representations. Thus, according to the ISO13584, form feature ontology includes two basic components to represent a form feature entity class: (1) a set of synonymy words that denotes the form feature and (2) a set of attributes that characterize the form feature. To avoid the defect of the distance-based method, we proposed attribute-based method according to the Rodriguez_EgenHofe model [21], and semantic similarity measurement can be performed as follows:

Suppose A_{f_i}, B_{f_j} is the set of attributes of feature f_i, f_j, respectively, semantic similarity measurement can be performed using the following equation.

$$Sim_U(f_i^A, f_j^B) = \frac{|A_{f_i} \cap B_{f_j}|}{|A_{f_i} \cap B_{f_j}| + \beta \times f(|A_{f_i}|, |A_{f_i} \cap B_{f_j}|) + (1-\beta) \times f(|B_{f_j}|, |A_{f_i} \cap B_{f_j}|)}$$

(8)

where

$$f(|A_{f_i}|, |A_{f_i} \cap B_{f_j}|) = \begin{cases} |A_{f_i}| - |A_{f_i} \cap B_{f_j}|, & |A_{f_i}| \geq |A_{f_i} \cap B_{f_j}| \\ 0 & \text{others} \end{cases}$$

(9)

$$\beta = \begin{cases} \dfrac{l_i}{l_i + l_j} & l_i > l_j \\ 1 - \dfrac{l_i}{l_i + l_j} & l_i \leq l_j \end{cases}$$

(10)

Definition 3-5 The map from graph G_A to graph G_B is denoted by $\rho: G_A \rightarrow G_B$ and $f_i^A \in V^A$. The degree of similarity between G_A and G_B at node f_i^A on map ρ is denoted by $S_\rho(G_A, G_B)|_{f_i^A}$, and the value of $S_\rho(G_A, G_B)|_{f_i^A}$ is defined as follows:

$$S_\rho(G_A, G_B)\big|_{f_i^A} = S_\rho(G_A(f_i^A), G_B(\rho(f_i^A)))$$

(11)

where

$$S_\rho(G_A, G_B) = \frac{\sum_{f_i^A \in V^A} F_{f_i^A}}{2(M_f + M_e)}$$

(12)

$$F_f = [M_f(f_i^A) + M_e(f_i^A)]S_\rho(G_A, G_B)\big|_{f_i^A} + F_f(f_i^A)$$
$$= \sum_{f_i^A \in V^A} \frac{w(f_i^A) + w(\rho(f_i^A))}{2} S_\rho(f_i^A, \rho(f_i^A))$$

(13) $S_\rho(G_A, G_B)$ is the linear sum of $S_\rho(G_A, G_B)|_{f_i^A}$ for all $f_i^A \in V^A$

The discussion above is based on one certain map only.

Definition 3-6 The map from graph G_A to graph G_B is denoted by $\rho: G_A \rightarrow G_B$. $S(G_A, G_B)$ is defined as the degree of similarity between graph G_A and G_B, and the value of $S(G_A, G_B)$ can be calculated by the following equation:

$$S(G_A, G_B) = \max_\rho(S_\rho(G_A, G_B))$$

(14) Equation (14) shows that the calculation process for similarity is an optimal solution-seeking process. This process is a combinational optimization problem.

During mapping, only when the value of similarity is greater than the threshold that mapping becomes meaningful. In other words, only when a similar map was found between different graphs that the similarity is meaningful.

Thus, when calculating the similarity between two simple families of parts, first, we must compare the similarity of nodes of different graphs. The similarity of any two nodes $S_\rho(f_i^A, f_j^B)$, which separately belong to G_A and G_B , is calculated. All of the values

$S_\rho(f_i^A, f_j^B), i \in N(V^A), j \in N(V^B)$ construct a matrix, which is named as node similarity matrix and denoted by S_ρ, and the dimensions of S_ρ is $n \times m$:

$$S_\rho = \begin{bmatrix} S_\rho(f_1^A, f_1^B) & \cdots & S_\rho(f_1^A, f_m^B) \\ \vdots & \ddots & \vdots \\ S_\rho(f_n^A, f_1^B) & \cdots & S_\rho(f_1^A, f_m^B) \end{bmatrix}_{n\times m}$$

(15) **Definition 3-7** For a given threshold N_{th}, for every $S_\rho(f_i^A, f_j^B) \in S_\rho$, if $S_\rho(f_i^A, f_j^B) \geq N_{th}$, then this pair of f_i^A, f_j^B is defined as a similarity element and denoted by $< f_i^A, f_j^B >$. At this time, only the map $\rho: f_i^A \to f_i^B$ satisfies $S_\rho(f_i^A, f_j^B) \geq N_{th}$; the map is thus useful.

Suppose the number of similarity elements in S_ρ is k, the map should be built between these similarity elements. In addition, based on the discussion above, the similarity of feature is not relevant to the map but relevant only to the features themselves.

The similarity measurement between two simple families of parts is translated into the following optimization problem:

$$S(G_A, G_B) = \max_\rho(S_\rho(G_A, G_B))$$

s.t.

$$\rho : G_A \to G_B 且 \forall < f_i^A, f_j^A >\in E^A, < \rho(f_i^A), \rho(f_j^A) >\in E^B \vee < \rho(f_i^A), \rho(f_j^A) >\in E^B \\ \wedge\ label(f_i^A) \cong label(\rho(f_i^A)) \wedge label(f_j^A) \cong label(\rho(f_j^A)) \tag{16}$$

where

$label(f_i^A)$ represents the feature type of node f_i^A, when the similarity of two nodes is $S_\rho(f_i^A, \rho(f_i^A)) \geq N_{th}$, let $label(f_i^A) \cong label(\rho(f_i^A))$; this time, the relationship between two feature classes are speculated to match each other.

For simplified and rapid computation, we propose the following Heuristic rules:

(1) When modeling a part in CAD system, the first step is to construct an entity, which will be subjected under various Boolean operations. Different Boolean operations will form different features. Thus, the similarity of these features formed by different Boolean operations is equal to zero.

(2) In FFDS graph, the higher the degree of node, the greater influence on parts model the node will be.

(3) The process feature should not be taken into account when constructing the FFDS graph to reduce the complexity of FFDS graph.

4. Case Study

Figure 11 shows three CAD models, and the similarity of these models can be calculated using our method, as follows:

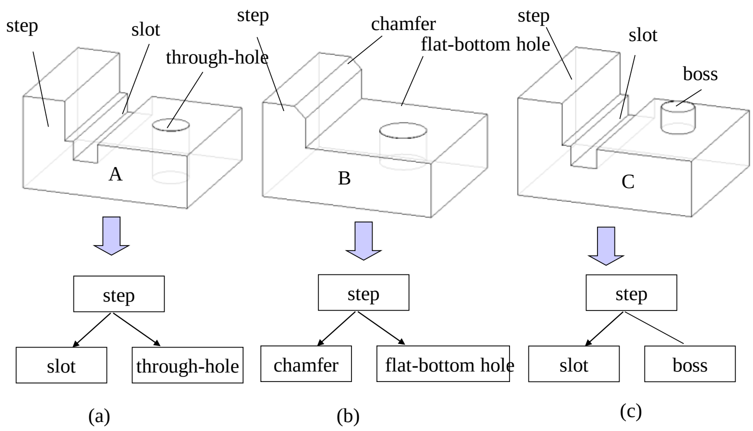


Fig. 11． Part model and its correspondent FFDS graph

Similarity measurement for parts A, B, and C (using the distance-based method; refer to Figure 3-12[18] for the classification hierarchy).

The similarity of feature class is as follows:

S(step，step) = 1，S(step，chamfer) = 0， S(step，flat-bottom hole) = 0

S(slot，step) = 0，S(slot，chamfer) = 0.06， S(slot，through-hole) = 0.06

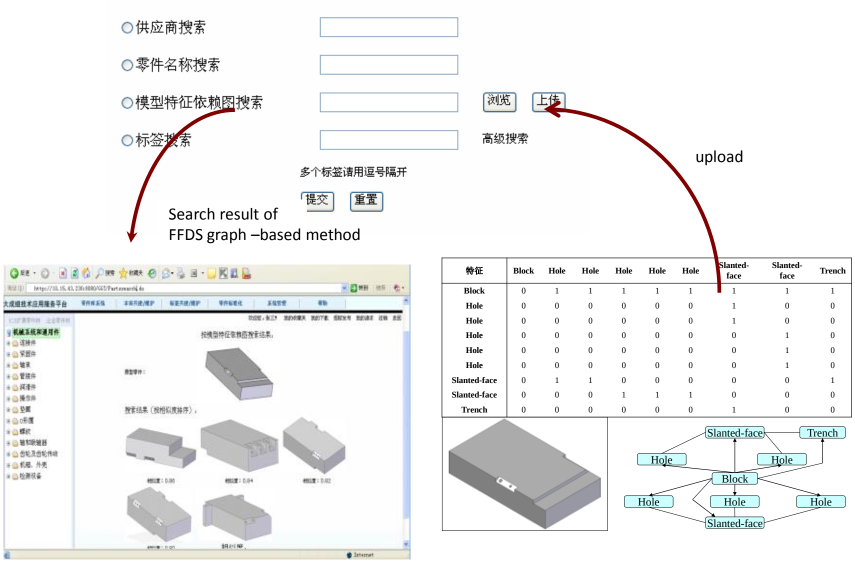
S(through-hole，step) = 0，S(through-hole，chamfer) = 0.05， S(through-hole，lat-bottom hole) = 0.6

The threshold is set at 0.5, and the similarity elements are {(step，step)(flat-bottom hole，through-hole)}

$$S(G_A, G_B) = \frac{(1 + 0.6) + 1}{3 + 2} = 0.52$$

$$S(G_A, G_C) = \frac{(1 + 0.67 + 0.6) + 2}{3 + 2} = 0.854$$

Figure 12 shows the similarity measurement procedure based on FFDS graph. The user can obtain the model's FFDS graph in CAD system (the semantic annotation is performed as shown in Figure 8). The user can then upload the FFDS graph file, which is defined as an adjacent matrix and can be saved in Excel format. Moreover, Figure 12 shows the search result.



特征	Block	Hole	Hole	Hole	Hole	Hole	Slanted-face	Slanted-face	Trench
Block	0	1	1	1	1	1	1	1	1
Hole	0	0	0	0	0	0	1	0	0
Hole	0	0	0	0	0	0	1	0	0
Hole	0	0	0	0	0	0	0	1	0
Hole	0	0	0	0	0	0	0	1	0
Hole	0	0	0	0	0	0	0	1	0
Slanted-face	0	1	1	0	0	0	0	0	1
Slanted-face	0	0	0	1	1	1	0	0	0
Trench	0	0	0	0	0	0	1	0	0

Fig. 12. A case of similarity measurement of part based on FFDS graph-based method

5. Conclusion

This study proposes an information model of supplier library that enables the interoperability and sharing of part information between parts manufacturer and complete machine enterprise. The technical features of this information model are as follows: (1) The supplier library is a two-level information model: ontology level and instance level. Part specifications is represented using the PLIB ontology to allow data integration and sharing between organizations. (2) The characteristics of parts are extracted from PLIB ontology model to construct an SML so that the supplier library can apply the "SML+ Master Model" technology [11] to represent and manage the part model in a simple family of parts mode. (3) A structured semantic graph reflecting the structure of parts is defined; the node of this structured semantic graph is based on form feature ontology[18， 22], and the edge of this semantic structure graph describes the topological relationship between features.

Similarity measurement among parts is one of the important issues in web-based parts library. In this study, we proposed a similarity measurement method based on structured representations (FFDS graph) of CAD model. Part search process starts with structured semantic model. This FFDS graph-based method is appropriate for collaborative relationship which illustrate in figure 1(b) and (c). For example, when a designer of complete machine enterprises completed the product design, the designer can start with the related part search based on the FFDS graph and identify the parts manufacturer that has similar parts production experience.

Future work will focus on the automatic extraction of the form features of parts and annotation of these features. Moreover, future work will improve the algorithm to achieve fast and efficient similarity measurement of FFDS graph.

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