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FUZZY LOGIC RETRIEVAL OF COMPLEX ENGINEERING INFORMATION

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1. Introduction

This paper analyses various aspects of information retrieval adapted to the process of conceptual design with a use of the common product data model (CPDM). The main idea is to provide for the extended and more flexible search of design patterns within the CPDM by applying data mining techniques including capabilities of multiple inheritance and classification. In this connection, the notion of complex engineering information defines all issues that can belong to more than a single design class with varying degree of membership. Especially, it is actual for the case-based reasoning in modeling the uncertainty of information.
The most important activities of flexible search are indexing, clustering and relevance ranking. Patterns indexing requires a finding appropriate design features to describe each pattern as well as cataloging those features in the CPDM. Patterns clustering allows appearing relevant information in multiple clusters to limit the number of patterns to be shown to a user. Ranking by relevance attempts to evaluate the degree of matching the user query with each of patterns in a cluster. There are many tools able to support these activities including a use of fuzzy set theory and connectionist (neural networks) theory [Yager 1999, Zadeh 1997]. However, the design process deals with information that must be structured. Furthermore, the user query includes functional requirements and parametric characterization (as opposed to feature characterization) of the object to be retrieved. In this case, the retrievable object becomes still more vague and uncertain. To face with this problem is to carry out additional research. Our proposal consists in integrating “top-down” and “bottom-up” search within the CPDM represented in the form of so-called fuzzy frame-based network.

2. Common product data model description

An underlying construct behind past developments of CPDMs was the template or prototype used for creating both actual product and design components representing it [Murdoch 1997]. Our model predicates upon the storage and processing design information with the help of frames. The feature is that each frame allows describing none one but different classes of design objects. Connected with each other into multilevel network, frames are capable to solve different problems of analysis and synthesis capturing descriptions of function, behavior and structure. The difficulty can arise from insufficient expressiveness of frames to represent adequately all relationships within graphical images. Therefore, we have to consider each design pattern in CPDM as organ structure with a text description to perform the actual search of graphical images on the text labels. Here, it is supposed that any organ structure can be represented by minimal number of the most important graphical images, which define in their aggregate both form and principle of operation of the given design pattern.

Fairly, one can emphasize only a few hierarchical levels of common mechanical product description. These levels are concerned with description of machines, assemblages, subassemblies and parts. In this case, the chosen images of assemblages can be taken for design organs in describing machines. Further, the chosen images of subassemblies become design organs for assemblages, the chosen images of parts become design organs for subassemblies and the chosen machine surfaces become design organs for parts [Napalkov 2003]. Thus, the retrieval process should consist of three stages:

- Determination of entitle of design pattern to be designed;
- Determination of graphical images associated with relevant design organs;
- Determination of graphical image associated with relevant organ structure.

The first stage is concerned with the target function input in accordance with the user query. Based on top-down retrieval, the second stage is concerned with analysis of requirements imposed on functions and parametrical descriptions of design patterns being taken for design organs. It includes a selection of appropriate frames used for finding indexes of design organs solving the user query. At the third stage, the found indexes are used for bottom-up retrieval of complex pattern of the object to be designed.

Allow for the notion of *fuzzy frame* to describe the CPDM more in detail. As usually this notion is introduced for storing multiple values of an object attribute in the form of fuzzy variables (also called the linguistic variables) [Sharma 2003]. Regarding the given CPDM, we deal with intersecting fuzzy frames, which form the network hierarchical structure based on functional decomposition of common product. In particular, analysing functions of parts we have categorized them on classes called as *rotating, moving, limiting, sealing, positioning, controlling* and *fastening*. For classification of subassemblies, the definition of different mechanical relations between parts has been taken for the basis. These classes have been called as *transference/rotate*, *transference/move, fix/position, fix/sealing, adjusting/limiting, adjusting/control, catching, mating* and others. Each of them represents certain *class frame* with organ structure composed from certain collection of other class frames for representing functions of parts, for example:

transference/rotate [*<rotating>, <positioning>, <sealing>, <limiting>*]*;*
transference/move [*<moving>, <positioning>, <sealing>, <limiting>*]*;…*

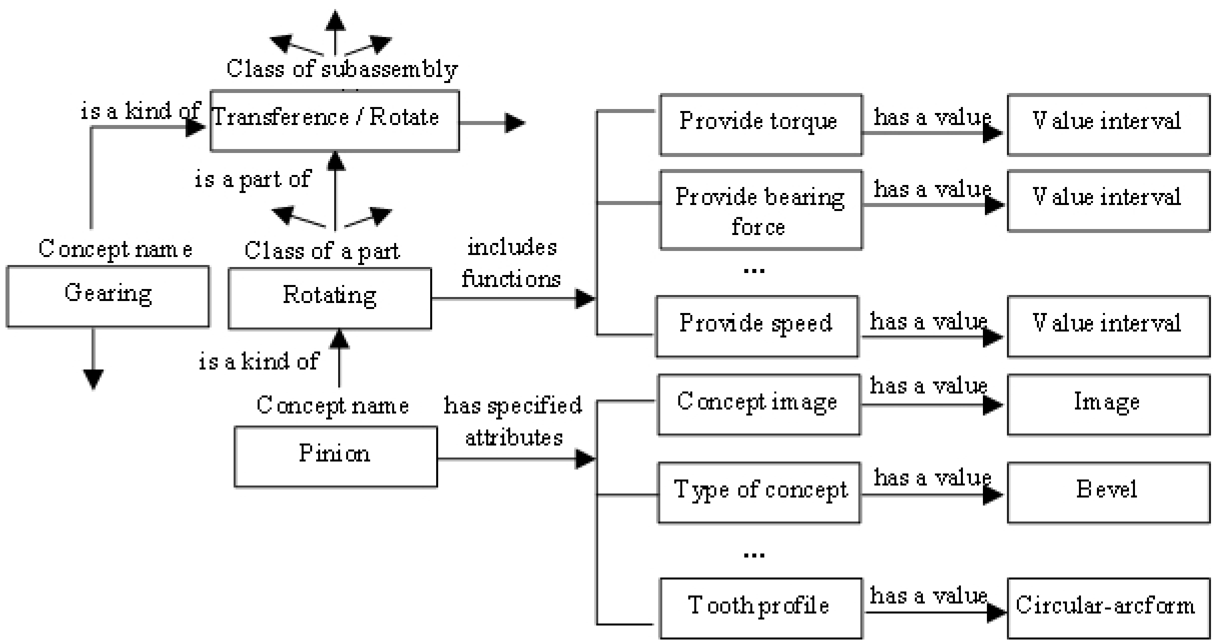

Figure 1. Example of class frame and instance frame interconnection in CPDM

By analogy, organ structures of assemblages are composed. For their classification, a type of the transferred energy (force, torque, pressure, temperature) has been chosen for major factor. These classes have been called as *driving, transference*, *adjusting,* and *fixing.* Examples of corresponding organ structures are:

transference[*<transference/rotate>,<transference/move>, <catching>,<mating>*]*;*

fixing [*<fix/position> , <fix/sealing>, <catching >, <mating>*]*;…*

Thus, only one class frame is used to represent organ structure of common mechanical product as a whole at the highest level of CPDM. As shown on Fig.1 the class frames are connected in network by means of relationship "is a part of…". For definition of concepts about individual design patterns, the *instance frames* are used. They are connected with class frames by means of relationship "is a kind of...". Besides, the class and instance frames contain different collections of properties defined as functional properties (or smaller functions) and specialized attributes respectively. The first ones are also used for representing functional requirements. For example, regarding the motor mechanics the function *Rotating* can be represented by constituents such as:

Provide a torque;

Provide a beaing force,…, etc.,

where these functions can be caused by different types of shafts, pinions and other parts with attribute values and images described in appropriate instance frames.

The described structure of CPDM allows appearing the same design concepts in different class frames. Therefore it is required the development of high-intellectual retrieval system to find relevant information. This impliyes our definition of the frame fuzziness (in contrast to above-mentioned definition of fuzzy frame) as the functional structure with uncertain composition of constituents identifyed as the result of evaluating multiple relationships between them in processing the user query.

3. General methodology of information retrieval for design application

Formally, the user query is formulated like "find the image of the design concept in accordance with the given target function <ssmall function name>, functional requirements <list of small function names> and attribute values <the extended parametrical characterization>".

Suppose that the user query q specifies the relationship $Q \subseteq P \times C$ being represented by Cartesian product of two sets such as some set P of specified attributes p and some set C of images c taken for design organs of the image to be retrieved.

Let $((p,c),\omega)^j \in [0,1]$ be a weight of the pair $(p,c)^j$, in which the attribute p is matched with the image c belonging to some concept of the jth class of design organs according to the relationship $Q^j \subseteq Q$. Then the total weight $(c,\omega)^j$ of the image c about the query q can be expressed in form of the Euclidean distance $d\,(c,q)^j$ between them defined as

$$(c,\omega)^j = \sqrt{\sum_p \| (p,c),\omega)^j - q \|^2} \ , \qquad (1)$$

where operation of summation is performed by identifying the specified attributes p of the image c.

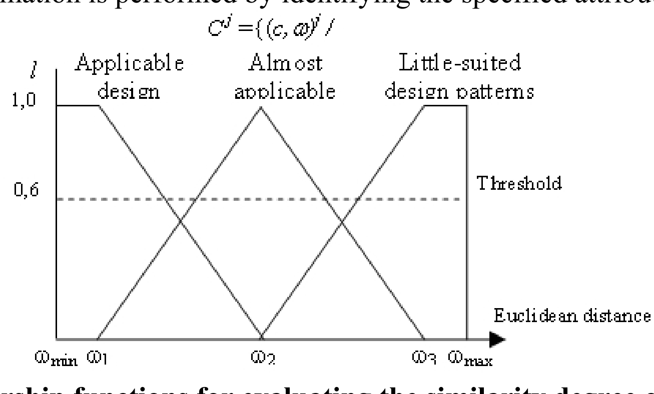

Figure 2. Membership functions for evaluating the similarity degree of design patterns

Representing the jth class of such images as a set $C^j = \{(c,\omega)^j / c\}$ allow the membership function $f: C^j \times C^j \rightarrow [0,1]$ to evaluate the similarity degree $f(c,\omega)^j = ((c,\omega), l)^j$ of each image in respect to the user query q, where l is a value of linguistic variable, $C^j \subseteq C$. For that, it is suitable to divide a set C^j into clusters according to three terms such as *little-suited*, *almost acceptable* and *acceptable* images about the query. Then one can assert that the linguistic variable l evaluates the similarity degree of image c by evaluating its membership degree with each of above-mentioned clusters. For clustering, we have used two trapezoidal and one triangular membership functions with standard parameters to be set by the designer. As shown on Fig.2 their representation foresees the assignment of three critical points $(\omega_1, \omega_2, \omega_3)$ in the common interval $[\omega_{min}, \omega_{max}]$ of measuring the Euclidean distanceFurther, let the relationship $G \subseteq C \times S$ denote some subset of specified pairs (c, s) generated for retrieval of relevant design patterns $s \in S$ with a help of design organs $c \in C$. In this case, it is necessary to identify all valid organ structures, which represent images s in accordance with existing instances of their given concept name. This operation can be performed by means of structural filtering as follows:

$$((c,\omega), l)^j \rightarrow (((c,\omega), l)^j, s)^i, \quad (2)$$

where (((c,ω), l) j , s) i denotes the similarity degree and the membership degree ((c,ω), l) j of the image c as some design organ of the image s, which belongs to the ith class of design patterns according to the relationship G i ⊆ G.
Hence, the total similarity degree and the membership degree ((s,ω), l)i of the image s can be computed by means of superposition (also called as aggregation) operation defined in following way:

$$((s,\omega), l)^i = \sup_j \{(((c,\omega), l)^j, s)^i / c\}, \quad (3)$$

where superposition operation is executed by identifying the specified design organs within valid organ structure of the image $s \in S^i$, $S^i \subseteq S$.
In particular, this operation includes: a) interpolation of local membership functions to define the term and value of the total linguistic variable l for the image s; b) defuzzification of local membership functions to define the total similarity degree ω for the image s.

Table 1. Structure of fuzzy retrieval rules for design application

Design organs similarity degree				Total membership degree $((s,\omega),l)^i$	
$((c,\omega),l)^1 \in$	$((c,\omega),l)^2 \in$	$((c,\omega),l)^3 \in$	$((c,\omega,l))^4 \in$	Term	Value
Applicable	*Applicable*	*Applicable*	*Applicable*	*Acceptability*	≥ 0.6
Applicable	*Applicable*	*Applicable*	*Almost appl.*	*Acceptability*	[0.0, 1.0]
Applicable	*Applicable*	*Almost appl.*	*Almost appl.*	*Acceptability*	[0.0, 1.0]
…	…	…	…		…
Little-suited	*Little-suited*	*Little-suited*	*Little-suited*	*Acceptability*	< 0.6

The basic structure of rules used for fuzzy logic retrieval of relevant design patterns is represented in the form of the decision matrix (Table1), where each row is some rule IF (some combination of linguitic variable terms to be assigned for weighting design organs) - THEN (total value of linguistic variable *Acceptability*). According to these rules, the system must retrieve among the most preferable graphical images with satisfactory threshold of applicability (a value 0.6 is applied). In the process of defuzzification, a computed value of total linguistic variable is automatically transformed in the Euclidean distance, for example:

IF ((c, 0.18), Appl.)1 ∧ ((c, 0.12), Appl.)2 ∧ ((c, 0.45), Alm.appl.)3 ∧
∧ ((c, 0.80), Little-suit.)4 THEN ((s, 0.489), Accept.)

that corresponds to *almost* a*pplicable* design pattern (it must be $\omega \leq 0.4$ for acceptable decisions).
The number of basic rules is no more 15 for any class of design patterns subject to the number of design organs in valid organ structure cannot be more than 4 for each class.
Representing the *i*th class of relevant and defuzzificated images as a set $S^i = \{(s,\omega)^i / s\}$ allow the weight-average Euclidean distance $\omega_i = \varphi(S^i \times S^i)$ between all pairs of such images. Then the common strategy supporting the retrieval can be defined as:

$$\text{Find } \{(s^*,\omega^*), \geq\} / \omega^* \leq \min \varphi(S^i \times S^i), \forall i \quad (4)$$

subject to the constraint (2), where $\{(s^*,\omega^*), \geq\}$ is an optimal ordered collection of relevant images, which can have different entitles of design patterns.
In order to extend the search limits it is acceptable to use strategies based on multiple classification and multiple inheritance. The first one has to retrieve relevant organ structures among design images related to the different class frames. The second one is aimed on a retrieval of design organs among design images, which have invalid organ structures with respect to the parent concept name.
In contrast to previous one, the strategy supporting multiple inheritance is carried out on total set *S* of specified pairs (*c,s*) without their structural filtering. This strategy requires the system operating in hypothesis generation mode. It is used in a lack of images corresponding to some definible concept.

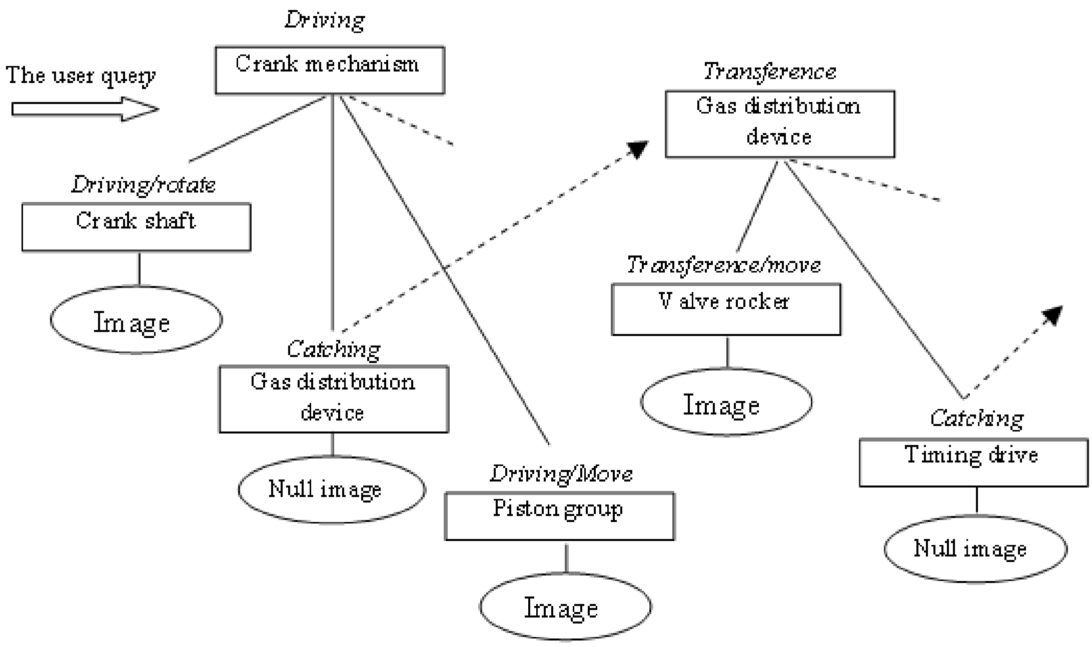

Figure 3. Example of deducing inference tree during the retrieval process

It means the need of jumping the system on higher level of the CPDM to continue the retrieval of these images among other class frames. Once this class is found, a new cycle starts to create the subordinate organ structure. The retrieval process is finished on condition that all found design organs would satisfy both functional and parametrical requirements. The result is a deduction of inference tree shown on Fig.3 as an example. Here, the target function (belonging to the class frame *Driving*) is formulated as *Transform the end-to-end motion into rotary motion.* Also the list of functional requirements includes small functions such as *Create the end-to-end motion*, *Force transfer to the rotary motion via pressure of gas mixture*, and others. Thereby, the organ structure with entitle *Crank mechanism* is generated.

4. Other applications

The problem of deducing valid inferences is closely concerned with maintaining the CPDM on a basis of structural and graphical interpretation of design patterns borrowed from external information sources. While the first process originates in the disclosure of technical content of design patterns via specifying types of their constituents in term of design entitles, the second process specifies graphical images of these constituents. Because of ambiguity of sensing borrowed design patterns, they can be portioned by alternative collections of functional and parametric properties. In this regard, it is usefull to consider the borrowed design patterns as fuzzy objects. Then one can define the task of fuzzy design patterns interpretation as the task of their defuzzification solved on the basis of searching relevant design constituents. The result is the CPDM extension due to creating new relationships between class frames and instance frames required for design reuse.

5. Conclusion

The described methodology of fuzzy logic retrieval is applied for capturing, structuring and analyzing engineering information required for functional design of mechanical products. It is based on the integrated approach to modelling the functionality of design patterns via matching their functions with fuzzy frames application. For this goal, the causal decomposition of common design functions has been made to create so-called the fuzzy frame-based network structure of CPDM. It is indicated that the retrieval process within such CPDM should support both top-down and bottom-up steps to decrease an uncertainty in decision-making. In order to realise the retrieval process the universal fuzzy logic rules based on measuring the similarity degree of design patterns have been developed. The main advantage is a creation of additional conditions for approximating the desirability of design functions and behaviors in selecting relevant graphical information during the design process.

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