FUZZY PRODUCT CONFIGURATION IN ADVANCED CAD SYSTEMS

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Today, configuring the mechanical systems and their components correctly so that they meet their functions efficiently and can be easily manufactured and assembled is crucial to effective product design. However, currently there exists no systematic and effective method for designing configurations. This paper proposes and develops a formal representation for supporting the computer-aided design approach for configuration. Two interrelated questions are taken into account: 1. What are configuration features? (Configuration feature concept);2. How can be constructed the design procedures capable to configure the product?(Computer-aided design approach for configuration). This approach, under the guide of the proposed formal representation, has been implemented in computers by using the functions of current CAD software.

1. INTRODUCTION

The design process is the series of activities by which the information known and recorded about the design product is added to, refined, modified, or made more or less certain. There have been many attempts to draw up models of the design process in systematic steps (French 1971, Pahl and Beitz 1984, Suh 1990, Albano and Suh, 1992).

In engineering design, to configure a mechanical system means to arrange the relative positions of its functional components and to determine what the functional components are to be (Dixon and Poli, 1995). The task of a system configuration is to select or determine what functional components the system will poses and how these functional components are to be arranged and connected in order to satisfy a set of requirements and a set of constraints imposed on the product (Tiihonen et al. 1996, Sabin and Weigel 1998, Brown 1998). Similarly, the task of part configuration is to select or determine what configuration features the part will posses and how those configuration features are to be arranged and connected.

When a mechanical system is decomposed into its components and associated couplings are specified, engineers are in effect determining and arranging its elements; that is, they are configuring the mechanical system. From the engineering point of view, the *system-component-feature* relationships are appropriate means for a general product representation. Since such means are recursive, any proper granularity level of representation must be introduced to assess design possibility.

Many attempts have been made for modeling the configurable products (Snavely and Papalambros 1993, Männistö et al. 2001, Siddique and Rosen 2001). However in CAD systems there are not the formal representation for supporting the designing configurations. Often, designers will generate only one alternative configuration, evaluate it subjectively, and then redesign by revising. The lack of trial configurations, missing of some creative or less obvious configurations, incomplete evaluations are some difficulties with a single alternative configuration process.

This paper proposes a formal representation for supporting the design for configuration. In the second part of the paper, an approach for basic configuration searching is presented. To solve the closer cases to real–world situations, it is proposed to enrich the part–configuration features and configuration features–configuration features relation with fuzzy logic. An example illustrates the proposed approach. Lastly, conclusions are presented.

2. BASIC CONFIGURATION SEARCHING

2.1 Configuration features

Configuration feature: concept for the representation of systems. Engineers do need concepts to represent their way of reasoning on the systems to be designed. This inevitable role is played by the configuration features.

Configuration feature: ontological concept. The selection of a set of configuration features indicates that engineers are not interested in other features. This consequence is inevitable because engineers have the opportunity to focus the attention on those aspects of the system that they believe relevant. The selection of an ontology in spite of the others can produce different views of the system to be designed.

Configuration feature: concept for the intelligent reasoning. This role is obvious because the initial design of configuration features is typically justified by how engineers can reason intelligently to configure. The intelligent reasoning, often implicit, can become explicit while examining the question of inference that configuration features propose and recommend.

Configuration feature: concept of computing. From a purely mechanic point of view, the reasoning is a process of calculus. Features offer ideas concerning the way to organize the knowledge that facilitate inferences. The content of the knowledge that they carry and the way of which this knowledge is represented, defines the efficiency of the computing. If one ignore the considerations of computing, then the knowledge represented by configuration features are inadequate for a real use.

Configuration feature: concept of communication. Finally, a configuration feature is a means of expression and communication. The relation between the possibility of a language based on configuration features and his utility, also the relation between the language utility and the facility of the utilization are some problems that surround the concept of configuration features.

2.2 Approach for basic product configuration

Engineering design can be considered as a process of reducing the uncertainty with each design alternatives is described. During the design process, the designer deals with some distinct forms of uncertainty: imprecision, randomness, fuzziness, ambiguity and incomplete (Deciu et al. 2005). The fuzzy set approach is particularly suitable for handling uncertain information by providing a set of solutions with different degrees of preference (Zadeh 1965, Bellman et al. 1970, Antonsson and Otto 1995, Kaufmann and Gupta 1988, Bahrami and Dagli 1993, Zimmermann 1996,). In this research, considering the fuzziness of handling uncertain design information, an approach for basic product configuration is proposed. This approach includes the three phases. The first phase, called configuration features based part model, consists of CAD parts representation based on the configuration features. The second phase, called configuration feature-configuration feature model, consists in representing the relationship between configuration features. The third phase, called basic configuration of product, consists in searching a preliminary configuration of product. The schematic chart of Figure 1 shows the architecture of this approach.

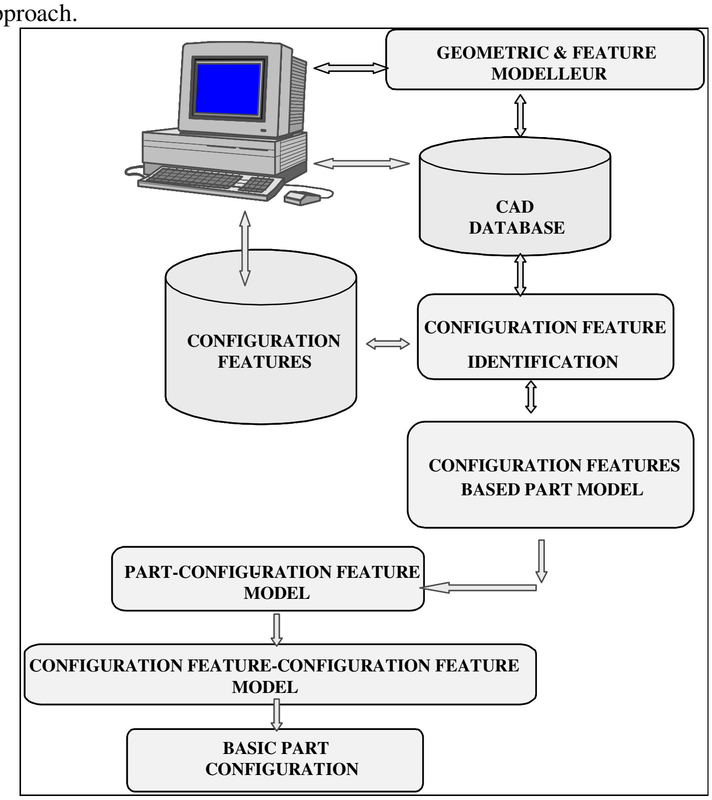
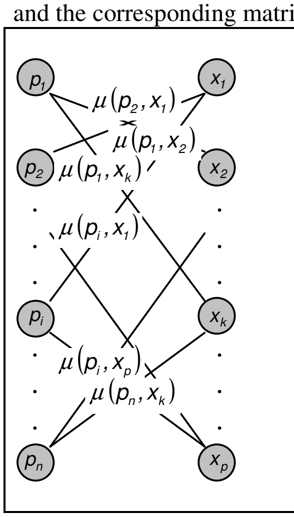


Figure 1 - Structure of the proposed approach

Configuration Features Part based Model. The most direct way to express the relationship between elements of two sets is to use ordered pairs made up of two related elements.

Let $P = \{p_1, p_2, ... p_i ... p_n\}$ be the set of parts in a database, and let be $X = \{x_1, x_2, ... x_j ... x_n\}$ be the set of features. Let R_1 be the relation that consists of those pairs (p_i, x_j), where p is a part containing the feature f. For instance, if the part "shaft" contains the feature "hole" then (shaft, hole) belong to R_1, otherwise (shaft, hole) is not in R_1. The relation between the sets $P = \{p_1, p_2, ... p_i ... p_n\}$ and $P = \{p_1, p_2, ... p_i ... p_n\}$ can be represented using a zero-one matrix. The relation R_1 can be represented by the matrix $A = [a_{ij}]$ where $a_{ij} = 1$, if (p_i, x_j) belong to R_1, otherwise $a_{ij} = 0$. However, in the case of the mechanical design, a finite set of manufacturing features can produce an unlimited number of configurations of manufacturing features in interaction. The information of feature membership to a part implies an uncertainty. This uncertainty means the existence of a fuzzy relationship $\tilde{R}_1$ between the set of parts P and subset of manufacturing features X, and therefore, between the set of parts P and the set of features X. This fuzzy relationship, noted $\tilde{R}_1$, is a subset of the Cartesian product $P \times X$ with the membership function $\mu_{R_1} \in [0,1]$ and it can be noted: $p_i \tilde{R}_1 x_k \quad p_i \in P, i = 1,2,\Lambda\ n; \quad x_k \in X, k = 1,2,\Lambda\ p$. The graph which represents the fuzzy relationship $p_i \tilde{R}_1 x_k$ is called the fuzzy part – operational feature graph, and the corresponding matrix is called the fuzzy part –feature matrix (Figure 2).



features

$$
\textit{parts}\quad
\begin{bmatrix}
\mu_{11} & \mu_{12} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\
\mu_{21} & \mu_{22} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\
M & M & O & M & O & M \\
\mu_{i1} & \mu_{i2} & \Lambda & \mu_{ik} & \Lambda & \mu_{ip} \\
M & M & O & M & O & M \\
\mu_{n1} & \mu_{n2} & \Lambda & \mu_{nk} & \Lambda & \mu_{np}
\end{bmatrix}
$$

Figure 2 - Fuzzy part-operational feature graph and its corresponding matrix

Configuration Feature-Configuration Feature based Model. Relation from the set $X = \{x_1, x_2, \ldots x_j \ldots x_n\}$ to itself is of special interest. Consider a simple example of the relationship between the features.

Let us consider the part p1 and its relationship with the set of features $X = \{x_1, x_2, \ldots x_j \ldots x_n\}$. The fuzzy relation between the features in $X = \{x_1, x_2, \ldots x_j \ldots x_n\}$, $x_i \tilde{R}_2 x_j \quad x_k \in X, k = 1,2,\Lambda\ p$ for the part p_1, is given by the fuzzy matrix $B_1 = \lfloor b^1_{ij} \rfloor$ where $\lfloor b^1_{ij} \rfloor$ is defined as minimum of pairs (p_1, x_i) and (p_1, x_j).

$$\left[B_1(x_i \tilde{R}_2 x_j)\right] = \overset{features}{\begin{bmatrix} \mu_{11} & \mu_{12} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\ \mu_{21} & \mu_{22} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \mu_{i1} & \mu_{i2} & \Lambda & \mu_{ik} & \Lambda & \mu_{ip} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \mu_{n1} & \mu_{n2} & \Lambda & \mu_{nk} & \Lambda & \mu_{np} \end{bmatrix}} \, features$$

In this way, one can process for each part p_i in the set P. Then, the fuzzy relation between the features in X, for the set of parts P, can be given by the fuzzy matrix $B = \lfloor b_{ij} \rfloor$, where b_{ij} is defined as the maximum value for all parts $b_{ij} = max\left(b^{p1}_{ij}, b^{p2}_{ij} \ldots\ldots b^{pn}_{ij}\right)$. This is a max-min operation. For example, the fuzzy relation between the features in X, for the set of parts P, is given by the fuzzy feature-feature matrix $B = \lfloor b_{ij} \rfloor$.

$$\left[B\ (x_i \tilde{R}_2 x_j)\right] = \overset{features}{\begin{bmatrix} \mu_{11} & \mu_{12} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\ \mu_{21} & \mu_{22} & \Lambda & \mu_{1k} & \Lambda & \mu_{1p} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \mu_{i1} & \mu_{i2} & \Lambda & \mu_{ik} & \Lambda & \mu_{ip} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ \mu_{n1} & \mu_{n2} & \Lambda & \mu_{nk} & \Lambda & \mu_{np} \end{bmatrix}} \, features$$

The matrix is symmetric and reflexive. This fuzzy relation is transformed into a similarity relation, which satisfies the transitivity. To define the consistent membership function between a pair of features, the maximum value for all possible routes can be taken. This is also a max-min operation.

Basic part configuration. The basic configuration of a part represents a maximal sub similarity relation. In this case, a parameter alpha can be used to indicate the strength of association between features to configure a part. The decomposition of the similarity relation into maximal similarities subrelations is based on the Boolean algebra.

Boolean algebra provides the operations and the rules for working with the set $B = \{0,1\}$. The variable is called a Boolean variable if it assumes values only from B. A function from B_n, the set $\{(x_1, x_2, ..., x_n) \mid x_i \in B, \ 1 \le i \le n\}$, to B is called a Boolean function of degree n. Boolean functions can be represented using expressions made up from the variables and Boolean operations. A Boolean algebra is a set B with two binary operations Boolean sum, denoted by (+), and Boolean product, denoted by (·), and a unary operation ($\bar{}$) such that the following properties hold for all *x, y* and *z* in B:

$x + y = x$ $x \cdot 1 = x$	Identity laws
$x + \bar{x} = 1$ $x \cdot \bar{x} = 0$	Dominance laws
$x + y = y + x$ $x \cdot y = y \cdot x$	Commutative laws
$x + (y + z) = (x + y) + z$ $x \cdot (y \cdot z) = (x \cdot y) \cdot z$	Associative laws
$x + y \cdot z = (x + y) \cdot (x + z)$ $x \cdot (y + z) = x \cdot y + x \cdot z$	Distributive laws

Given the similarity relation and the value of the parameter alpha, used to indicate the strength of association between features, how can a Boolean expression that represents the maximal similarities subrelation can be found? This problem is solved knowing that any Boolean function may be represented by a Boolean function may be represented by a Boolean sum of Boolean products of the variables and their complements. For searching the maximal similarities subrelation, the following algorithm is used (Pichat, 1969):

Step 1*: Consider the first row.*

Step 2*: Consider all zeros in the considered row.*

Step 3*: For every zero, considering the elements corresponding to columns as Boolean variables, form:*

Boolean Product (.) between the corresponding elements of columns where the zeros are;

Sum booléienne (+) between the element, which denote the considered row, and the Boolean product. If not zero is in the row, the sum is equal to 1.

Step 4*: Repeat the steps 2-4, until all the rows are considered*

Step 5*: Form the product of results. A Boolean function is obtained.*

Step 6*: Take complements of every term. The maximal subrelations of similarities are found.*

3. APPLICATION

Let us consider a representative subset CAD parts and a set of pertinent features *{a,b,c,d,e,f}*. After the recognition process of features, the feature-feature model is given in the figure 3.

	a	b	c	d	e	f
a	1	0.72	0.8	0.9	0.12	0.84
b		1	0.24	0.84	0.32	0.94
c			1	0.9	0.24	0.32
d				1	0.18	0.91
e					1	0.88
f						1

Figure 3 - Feature –Feature matrix

Using a threshold value ($\alpha \geq 0.5$), the Feature-Feature matrix is transformed into a binary matrix (Figure 4).

	a	b	c	d	e	f	
a	1	1	1	1	0	1	a+e
b		1	0	1	0	1	b+ce
c			1	1	0	0	c+ef
d				1	0	1	d+e
e					1	1	1
f						1	1

Figure 4 - Feature –Feature matrix ($\alpha \geq 0.5$)

Applying the algorithm, the results from the step 1 to the step 4, are given on the left of the figure 2. The following Boolean function results in the step 5:

$S = (a+e)\cdot(b+ce)\cdot(c+ef)\cdot(d+e)\cdot 1\cdot 1$

After applying the properties of Boolean algebra, this function is reduced into:

$S = abcd + ce + bef$

The complements of every terms, give the maximal sub relation of similarities:

$S' = ef + abdf + acd$

Here, the terms *ef, abdf,* and *acd* represent the basic configuration for three maximal parts in term of the strength ($\alpha \geq 0.5$) between their respective features. The first maxima part is composed by the features e and f; the second maximal part by the features a,b,d,f; and the third maximal parts by the features a,c,d.

4. CONCLUSIONS

Currently there exist no systematic and effective methods for designing configurations. The lack of trial configurations, missing of some creative or less obvious configurations, incomplete evaluations are some difficulties with the one alternative configuration process. This paper proposes and develops a formal approach for supporting the computer-aided design approach for configuration based on the concept of configuration features and the fuzziness.. The characteristics of design for configuration are described by resorting the structural relationships between configuration features, which are very strong in design. The fuzzy configuration feature-part and relation are used to compose the fuzzy configuration feature-feature configuration, which is represented by the corresponding matrix. After fuzzy configuration feature-configuration feature matrix decomposition, the maximal sub relations of similarities. They correspond to the initial product configuration. Configuration features and fuzziness provide a means to include the flexibility in designing the basic configuration. This flexibility depends on the chosen threshold value. The subsequent CAD modelling is implemented in computers by using the functions of current CAD software.

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