Conceptual functional-to-form mapping for green design

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Abstract. Design for dis-assembly (DFD for short) is the key issue for green design automation. In this paper an assembly-level function-to-form mapping CAD system is reported for green design computing. The research work mainly includes: the assembly-level function definitions, product network model, two-step mapping mechanisms, dis-assembly sequencing based on graph theory, dis-assembly analysis etc. The function-to-form mapping is divided into two steps, i.e. mapping of function-to-behavior, called the first-step mapping, and the mapping of behavior-to-structure, called the second-step mapping. After the first step mapping, the three dimensional transmission chain (or 3D sketch) is established, and the product network model is created, on the basis of which the assembly/dis-assembly analysis and sequencing of the whole mechanism could be fulfilled. A mechanical hand is illustrated to verify the feasibility of the design methodologies.

1. Introduction

Green green is divided into the following several contents, 1) Computer-based representation of product specifications; 2) testing of product performance against the product specification. 3) design intent management with LCA inventories, where design intent management and the interface for acquisition, representation, analyzing, recording and retrieving of the user’s intent information from the product life cycle design perspectives are outlined. 4) Product oriented assembly/disassembly (DFA/DFD) [1,2] analysis, optimal product assembly/disassembly sequence planning and design methods[3] and components maximum reusability design method [4,5]; 5) design method for recycling, recovery and recycling of waste products into the design of the assessment; Life Cycle Assessment (LCA for short) [6] etc. Traditionally, Suh.N.P [7], Yoshikawa.H [8], etc laid down the traditional design theories. So far, traditional CAD systems make use of the manifold entities, where, feature modeling, feature recognition and feature mapping, etc, based mainly on specific quantitative information [9], i.e. the design theory and methodologies cope with DFX (X means, A:Assembly, C:Cost, D:Disposal, F:Function, M:Manufacture, Q:Quality, R:Recycling, S:Services and T:Test) etc.

However, conceptual design systems should have the following functional features, i.e. the visualization of uncertain entity; growth and expansion of uncertain entity; adaptive and dynamic
growth of the entity model within a specific design. Therefore, default logic reasoning [10] is applied to the study of geometric entity reconstruction under uncertain information, and a new theory of default geometric reasoning[11] is proposed. Automatic mapping among design domains could dramatically increase exploration proficiencies etc.

And reconstitution algorithms evolving default logic is to cope with ambiguous information occurred in conceptual design stage, which is also effective exploration tool for concept creation and visualization, called exploitation. The F-F mapping model cooperating axiomatic design theory is proved to be effective to integrate requirement, function and form domains for a creative design tool.

2. Function-to-form mapping for green design

Let $U$ be a functional domain (Function Requirements, referred to as $FRs$), $V$ is the domain (Design Properties, referred to as $DPs$), $P (U), P (V)$ is the power set of $U,V$, $FRs \subseteq P(U), DPs \subseteq P(V)$.

$\text{Definition 1, functional carrier, if there exist transitional domains, between functional domain and form domain, called } CRs, \text{ make } x \in CRs, \text{ if and only when } x \text{ satisfies the following two terms:}$

- A simple, intuitive, deterministic correspondence that satisfies $FRs$ to $CRs$
- At the same time, mapping from $CRs$ to $DPs$ satisfies the ‘deterministic’ criterion, where ‘deterministic’ is referred to as reconfigurability.

Figure 1 is the generalized mapping process model of green products design. This model describes the demand analysis, functional design, function-to-form mapping, form reconstitution etc, in a "top-down" style. The green product requirement model similar to the LCA (Life Cycle Assessment) system, acted as the top constraints. These constraints are propagated to the function domain, functional carrier domain, form domain etc. The green design requirement LCA model support the design process automation.

![Figure 1. Function-to-form mapping for green design.](image-url)
3. Management of green design system

In view of the special requirements of green product design, the functional requirements of easy manufacturing, the functional requirements for easy assembly/disassembly, the functional requirements for the maximum reuse value of product parts, etc, are put forward, as in figure 2.

Green products involved many research fields, including: A. requirement domain GRA. B. green product function domain GFR; C. green product functional carrier domain GDPS. And d. green product functional domain GDPS. Green product design is to complete the mapping of generalized domains from A, B, C, and D. The mapping results are the D form domain, which is consisted of discrete feature/functional face sets etc.. The comprehensive reconstruction is to completed the structural innovative design of the product.

![Diagram of green design automation system](image)

**Figure 2.** Green design automation system.

Green product design put forward higher requirements than the traditional mechatronic design, these higher requirement are expressed in the basic product attributes, energy characteristics, manufacture/assembly characteristics, environment characteristics, energy characteristics and resource characteristics etc. Traditional CAD systems do not consider these higher requirements, so it is difficult to achieve high quality product design in an efficient and innovative way. So this research on green product innovation design automation has significant social and economic benefits.

4. The green design process model

The functional characteristics of the green product DFA/DFD analysis method based on automatic analysis structure to realize the product life cycle, and provide design recommendations, as in figure3.
Based on the "strong points map" theory of complex product structure assembly / disassembly sequence planning and design, and based on the concept of generalized double bonds, "green products" optimal "assembly / disassembly sequence planning analysis and design.

5. Product assembly model based on functional features
After function-to-form mapping (F-F mapping for short), the product conceptual model has been established, the conceptual product model is composed of functional faces and their correlations. There are three levels in an assembly model of one product.

According to the functional requirement of support, stop, fixing or positioning etc, different features are mapped to the corresponding parts, so one specific feature is mapped to two or more corresponding parts, and the relationship between parts in a product are naturally established, as in figure 3. The Sub-functions in figure 3 mainly refers to the functions of drive, location, clamping, sealing, blocking, etc. for motion function motioni, after F-F mapping, a meta_element is formed, defined as meta_elementArray. Based on the product assembly model, the features are expressed in the assembly, and the relationship between features and features, parts and features, and parts and parts etc, with the information of location, size, constraints etc, are defined in a data structure to describe the three types of relations, as in figure 4.

6. Dis-assembly analysis based on the relative motion matrix

After the function-to-form mapping, functional features are created, one functional feature is mapped to one part as the active feature, the other functional feature is mapped to another part as the re-active feature, and the correlation of the two parts are set up. The relative motion matrix is therefore establish based on the part-net and GPAL_KN.

Take the four parts assembly in figure 5 as one example, the connection in XY plane is established in table 1, where “1” means the part can be moved, “0” manes, the part can not move. There are six numbers to illustrate, -X, Y, -Y, Z, -Z directions respectively. For example, in table 1, column 2 and row 3, there is six numbers, i.e. 0,0,1,0,0,0, means part A can move relatively to part B in the -Y direction, and it can not move in the rest 5 directions. If two parts do not contact, the two parts can move in any direction relatively.

|    | A     | B     | C     | D     |
|----|-------|-------|-------|-------|
| A  | 1,1,1,1,1 | 0,0,1,0,0 | 1,1,1,1,1 | 1,0,1,1,0 |
| B  | 0,0,1,0,0 | 1,1,1,1,1 | 1,0,0,0,0 | 1,1,1,0,0 |
| C  | 1,1,1,1,1 | 0,1,0,0,0 | 1,1,1,1,1 | 0,0,1,0,0 |
| D  | 0,1,1,1,0 | 1,1,0,1,0 | 0,0,1,0,0 | 1,1,1,1,1 |

Note: 1. the two parts that are not connected in the connection diagram is set as: "111111111111".

2. The data of the relative motion matrix between any two connected parts is determined by the mapped features.

The dis-assemblity of any one part in an assembly can be analyzed by the relative motion matrix. The specific methods are as follows: take part B as the example, in table 1, find the corresponding partB in a row or column, look at the part B and other parts in the space with the same moving direction {x, -x, y, -y, Z, -Z}, if the number is “1” in one direction, then it can move in this direction, i.e. it can be disassembled in this direction.

If the number is “0”, then it can not be dis-assembled in this direction. In the vector {0,0,1,0,0}, there is one “1” in the -Y direction, means part A in -Y direction can be removed.
7. Case study

Requirement analysis, there are many special considerations for green product design. Firstly, LCA oriented requirement domain need to be added to the generalized mapping process model and to increase the performance of the CAD systems. Secondly, product DFD/DFA requirements are also needed to add to the CAD systems; for the product assembly/disassembly analysis and path planning, etc. The higher requirement are for the product disassembly analysis and sequencing, for the parts reuse in the most economical way; and lastly, for product renovation design, re-manufacturing (de-manufacturing) design etc.

![Fig 6. Green design requirement module.](image)

To clamp one work-piece, the mechanical hand have the opening and closing movement, the Behavior1 can be further decomposed into a transmission principle diagram as shown in Figure 7(a).
Stepping motors is firstly selected interactively. The stepper motor is related to several parts as, drive parts, nuts, screw drive components. In combination with figure 7 (a), the 3-D transmission chain of the mechanical hand is deduced, as in figure 7(b), and the corresponding parts of the product are created at the same time.

As shown in figure 7 (a), from the driving principle of the mechanical hand, four correlated parts are created, namely, Part1, Part2, Part3 and Container.

Table 2. The relationship between the created parts and the resulting meta bodies

| function | meta_element         | Parts involved                      |
|----------|----------------------|-------------------------------------|
| Motion0  | F01(Cylinder), F02 (plane) | Part1, Container                    |
| Motion1  | F11(thread)          | Part1, part2                        |
| Motion2  | F21(Cylinder), F22(plane) | Part1, Container                    |
| Motion3  | F31, F32, F33, F34(plane) | Part2, Container                    |
| Motion4  | F41(double), F42, F43(Plane) | Part2(F411, F412(plane)) part3(F413(cylinder)) |
| Motion5  | F51(cylinder), F52, F53(plane) | Part3, Container                    |

Table 2 illustrates the five motion in the mechanical hand, meta_elements are firstly deducted. For example, the meta_element F41 is deducted by the motion4, F41 is mapped on Part2, and the corresponding feature, F411 and F412 are created, in the mean while F412 is created on Part3.

And the relationship between the two parts, i.e. Part2, Part3, and the corresponding features F411, F412 and F413 are established. The functional surface sets of Part1, part2, and part3 formed by the function structure mapping are shown in figure 7(b).
8. Conclusion
An effective assembly level function-to-form mapping model is proposed in this paper. It could be concluded that, the decomposition, F-F mapping and reconstitution model could be a common exploration, transformation and exploitation procedure for management of computational design tools, therefore helpful for creative work, specifically the synthesizing of form domain is not simply re-arrangement of physical elements, rather it needs geometrical as well as algebraic reasoning on un-manifold polyhedral. Novel mathematical as well as AI technologies need to be introduced. Several packages of design tools have been developed to testify the effectiveness of the design methodology.

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