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ORIGINAL ARTICLE

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An online Web-based environment for detailed design reuse

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Abstract This research presents an online Web-based environment for the reuse of detailed design. In this environment, users can browse existing product databases including all related product information and graphic displays of the geometrical models, search and retrieve related products and generate new designs from existing products. In the underlying database, product data are clustered into product families to facilitate data management and reuse, and the variant method is adopted to transform an existing design into a new design.

Keywords Design reuse · Detailed design · Online environment · Product design · Product family · Variant method

1 Introduction

Designreuse is a practice that almost always accompanies product design. It is estimated that 90% of all industrial designs are adaptive or variant [1]. This means most of the design problems are solved by making use of existing designs in some way rather than being designed from scratch. Design reuse is vital to reducing development costs and lead-time while maintaining stable design quality in an ever-changing and highly competitive market.

Design reuse happens in many ways. The design problem-solving process consists of fours phases [2]: problem clarification, conceptual design, embodiment design and detailed design; the form and substance of design reuse at difference phases vary respectively. Detailed design is the final and output stage of the design process. Hence, design reuse activities will influence the reuse of detailed design. Research on detailed design reuse is therefore of great importance, and forms the foundation for design reuse in other phases.

Since the detailed design phase is so far the most explicitly understood and computerised phase in the design process compared with other phases like conceptual design or embodiment design, much more effort has been devoted to this area, and many prototype systems have been developed. Related research issues include detailed design data-storing methods [3, 4], database construction [3, 5], related feature-extraction techniques and geometrical data similarity evaluation [5], development of standard languages for detailed design description and product modelling [6], functionality capturing of detailed design data [3, 7] and finding appropriate methods to retrieve detailed design data [8]. These efforts, to some extent, embody Duffy's design-reuse-model [9]; namely, design-by-reuse, design-for-reuse and domain-exploration. For example, functionality-capturing of detailed design data, which is conducted during product design, is a form of design-for-reuse, and the functionality recorded can be used as a searching index for product data retrieval; design description languages and the methods for storing and for database construction are designed to facilitate product representation, recognition, information extraction and retrieval, which are issues falling into the scope of domain exploration.

Despite progress in this area, most of these researches and many of the prototype systems are implemented on a single computer or workstation as a standalone system based on a certain solid modeller [10, 11]. However, the design realisation process has become more and more globalised and distributed, and other product development life-cycle activities like marketing, manufacturing, etc., have become tightly interwoven with design [12]. Under these circumstances, a standalone system obviously cannot fulfil this need, and an open environment that can be easily accessed to assist product design by reusing previous design is of great importance and benefit. It will greatly promote the understanding and utilisation of previous designs, as well as the evolution of new design.

The rapid development of information and Internet technologies provides a suitable infrastructure and techniques for the development of such design environments. The Web-based online environment for detailed design reuse presented in this paper allows user to reuse previous detailed design data by visiting the online servers via the Internet from anywhere without the need to directly handle the 3D geometrical data with a specific CAD

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system. In this environment, users can browse previous designs, search for relevant designs and create new designs based on them.

The Web-based environment is made up of two server programs – an HTTP server and a UG/Open API server program in a UNIX host. The two server programs communicate via the Internet. In this environment, all product data are clustered into product families based on their functions and geometrical similarity to facilitate data management. In addition, the variant method is adopted to generate a new design from an existing detailed design.

In the present paper, Sect. 2 gives a general description of the architecture and the operation of the Web-based design environment that has been developed in this research. Section 3 provides some related background on product family, variant methods and feature-parametric-based modelling. Section 4 presents a detailed explanation of specific operations on the environment. Section 5 explains some considerations of system implementation. Finally, the conclusion is presented in Sect. 6.

2 System architecture

As shown in Fig. 1, as with all other online service systems, users can just access and interact with the HTTP server in this design reuse environment using the common Internet Explorer. All users' requests relating to product geometrical data will be diverted to the UG/API server program. Like all online service programs, data management is an indispensable component. In this system, there are two kinds of data – one is text-based product information data, and the other is geometrical data. The former is stored in a relational database and is called and processed by the HTTP server program, while the latter is stored in the form of UG part files residing on an online UNIX host.

2.1 HTTP server program

There are three main functions for the HTTP server program; namely, product data browsing, product searching and retrieving, and communication with the UG/API server program. These three functions are briefly described next.

Product data browsing. Users can browse the hierarchical structure of the complete design database. At the same, users can also view the detailed description of any specific design with a graphical display.

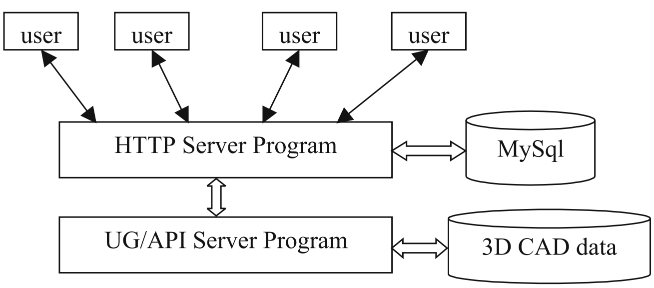


Fig. 1. Online Web-based environment for detailed design reuse

Product searching and retrieving. The server program takes in the users' design input, such as the functional requirements or other searching criteria, and searches the design database to retrieve the most approximate ones to reuse.

Communication with the UG/API server program. Users' requests relating to geometrical data processing will be sent to the UG/API server program via the Internet socket communication. Next, the HTTP server program will receive feedback from the UG/API server program to answer the users' requests.

2.2 UG/API server program

The two main functions of the UG/API server program are detailed design reuse and graphical file generation.

Detailed design reuse. The UG/API programs are capable of generating new detailed designs from existing design data based on the variant method.

Graphical file generation. Currently, due to the bandwidth bottleneck of the Internet, it is still not viable to display original CAD data files, such as UG part files in this system through the Internet. However for product design, graphical displays are vital for understanding. Hence, in this system, the virtual reality modelling language (VRML) file format is adopted for online graphical displays. Each time a user browses certain design data or tries to reuse it, the UG/API server program will instantly generate an up-to-date VRML format file of the design and send it to the HTTP server for display.

2.3 Design descriptions and data structure

In the present online Web-based system, the description of a specific product design consists of two parts – product attributes and a geometrical model. The product attributes include functions, key characteristics, cost, etc. They are all text-based, and are stored in a relational database. As for the geometrical models, all 3D models are stored in the UG part file format and reside on an online UNIX host.

3 Background

Before going further to describe the specific operations in the design reuse environment, some background methods are presented in the next section, and their applications to the online Web-based system are addressed.

3.1 Feature-based parametric modelling

This is the most widely used modelling method in mainstream solid modellers. It is a combination of the feature-based and parametric-based modelling methods [6, 13]. In feature-based modelling, a solid model is constructed by combining features like blocks, cylinders, holes, chamfers, etc. Parametric-based modelling offers the ability to parameterise various geometrical aspects of design models, generally to set various dimensional elements of the model geometry, such as the length, position, diameter, etc. These parameters can be assigned physical, numerical values and can be altered at will. The feature-based parametric modelling approach modularises the geometrical modelling and makes it easier and more intuitive to make use of existing 3D models and to modify them. It largely facilitates the process of detailed design reuse; for example, to generate a new detailed design based on some existing designs, a user simply needs to decide which features to add or remove and which parameters to alter. The solid modeller will then generate a solid model for the new design [4, 14–16].

However, the feature-based parametric modelling approach is not directly implemented in the system as described above. It is combined with the concept of "product family" to facilitate further reuse and data management.

3.2 Product family and variant method

Theconcept of "product family" has different meanings at different product life cycle phases, and is implemented in different manners. In this system, products that share the same functions and have similar geometrical structures are clustered into one product family. The reason to do so is to simplify product data management and facilitate data retrieval and reuse. This also allows the concept to be easily implemented with the UG/Open API.

A product family can be seen as a virtual spreadsheet that records information of a group of products. It consists of two parts – the family definition and the member data. The family definition is made up of a series of characteristic features and parameters of the products that are mostly of concern to the designers. The member data include the ID of the member products and the values of their attributes for the family definition. The value for a feature attribute is either yes or no, indicating whether the feature is included or excluded in the member product. For the parameters, the values are simply the desired numerical values for the individual member products.

In the Web-based system developed in this research, in order to reuse an existing design, a user needs to provide all of the desired values for all of the family attributes, and a new member product will be added to the family. If the user wants to control more features and parameters, he or she can edit the family definition by adding in more attributes. This method to generate a new design is actually the variant method. In variant method, there is usually a "master model" that contains all of the combined features of a family of designs. The master model is used to build an instance of an individual family member [4].

4 Detailed descriptions on operations

4.1 Product data browsing

Since the online Web-based environment is based on dynamic Web-pages, it takes advantage of the cross-referencing feature

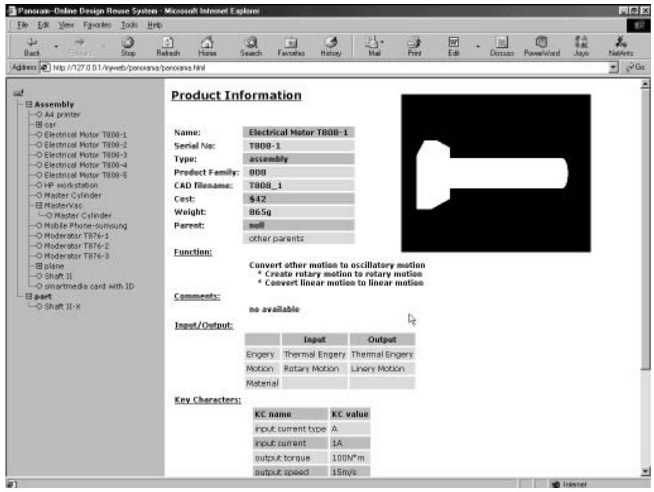


Fig. 2. Product profile interface

of hypertext markup language (HTML). In the information page of each product, related products within the product hierarchy or the peer products in the same product family are listed, and users can access their profiles by simply clicking on their name. Figure 2 shows a product profile interface.

4.2 Product searching and retrieving

The searching and retrieving process largely determines the performance of a design reuse system. The relevance of the search results mostly depends on the indexing methods of the product data and the design of the searching mechanism. In this Web-based environment, almost all kinds of product attributes are indexed in some ways, and a step-wise eliminating searching mechanism is implemented. Users can retrieve data using one index or a combination of several indices. When many products have been retrieved, the users can screen out irrelevant products by adding in more search criteria. Figure 3 shows the prod-

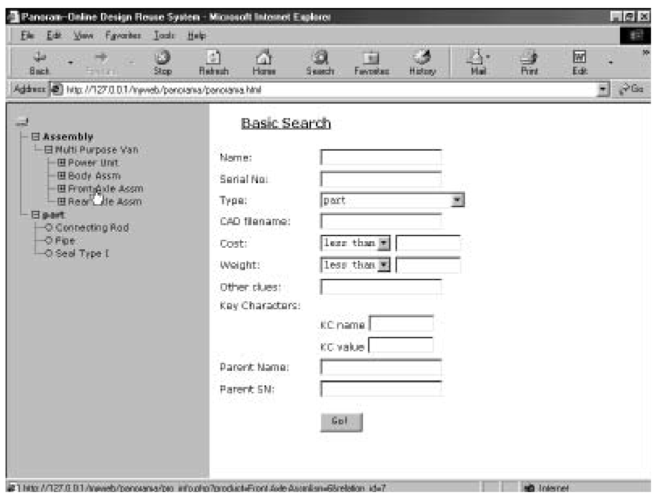


Fig. 3. Product search interface

uct search interface and Fig. 4 shows the interface displaying product search results. Figure 5 illustrates the step-wise search mechanism in the design reuse environment.

As mentioned above, the product attributes are indexed in some ways, and a step-wise eliminating searching mechanism is implemented. The accuracy and relevance of the searching mechanism largely depend on the way the data are indexed. In this implemented system, existing product data are indexed based on the first 13 entries in Table 1. Besides the product data being multi-indexed, the users can customise the search criteria by combining as many indices as they wish. In addition to the multi-indexing method, different detailed retrieving methods are also supported according to the nature of the different indices. For example, for indices such as functions and comments, which are usually highly diversified in the natural form of language, users can input keywords as desired, separated by commas, and the system will retrieve the data that satisfy all of the keywords regardless of their order. For certain quantitative indices such as cost and weight, users can choose to search for products that are more than, less than or equal to a given value. For key-characteristics that are different for different products, the users can search using the name, value, unit or all of the above.

A step-wise winnowing searching mechanism is implemented in this system. This feature gives users more flexibility in the searching process while traditional data retrieving allows little user intervention. The advantage of stepwise-winnowing lies in the fact that users need not give full search criteria at the first instance. The searching result of each step will be stored in a temporary database table and presented to the users. Users can refer to them and decide how to narrow down the search by

Table 1. Product Profile

	Name	Comments
1	Product name	Name of the product as in the technical documents
2	Product serial number	Serial number of the product as in the technical documents
3	Type	Assembly or part
4	Product family	The index of the product family to which the product belongs. Users can explore the product family profile by clicking on the product family name
5	CAD file name	The UG part file name of the product in the UNIX host.
6	Cost	Cost of the product
7	Weight	Weight of the product
8	Parent	The product in a higher level of the product hierarchy, to which the current product belongs. As one product may be a component for many products, all of its parent products are listed, and clicking on the name of the parent product will lead to its profile page
9	Function	The function description of the product
10	Additional comments	All other comments about the product are listed here. They are usually remarks about some unusual aspect of the product
11	Input/output	Three kinds of input/output (I/O) information are presented – energy, motion and material
12	Key characters	The name of KCs of the product and their values
13	Product family details	A table including all of the geometrical details of all members of the product family. The current product member is highlighted. By referring to the graphic display of the product, users can achieve a good understanding of the physical structure of the products in the family
14	Detailed reuse option	This is an interactive user interface with which the user can achieve the reuse of the CAD model to generate a new design. It is the entry of the design-transformation module
15	Graphic display	An embedded virtual reality modeling language (VRML) file presents the graphical 3-dimensional (3D) model of the product

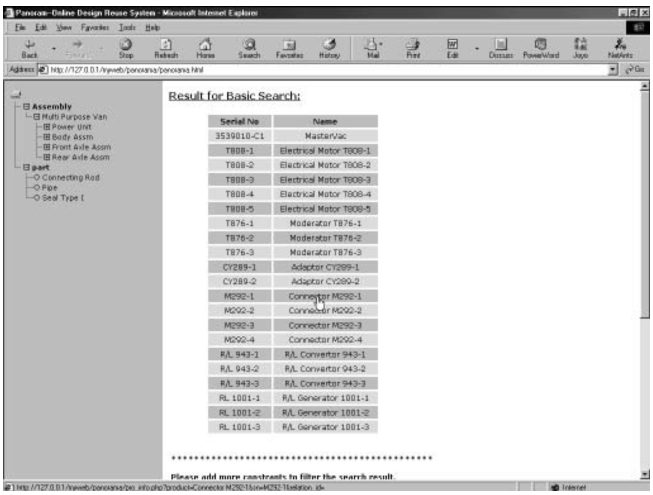
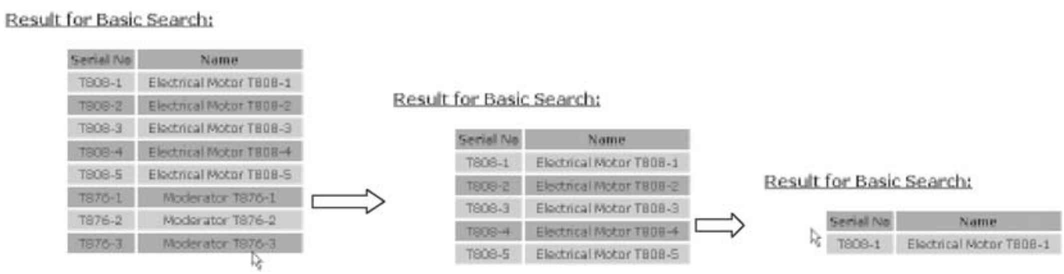


Fig. 4. Product search result page

Fig. 5. Illustration of step-wise searching



adding additional searching criteria to winnow out the irrelevant data among the previous searching results.

In addition to the above multi-indexed searching mechanism, an advanced searching mechanism has also been implemented to provide a more intelligent and robust way to retrieve reusable products. Four sub-modules are defined in this advanced searching mechanism; namely, the function-analysing, product-family-retrieving, alternative-solution-generating and product-retrieving sub-modules [17]. With the features discussed above, the retrieving efficiency is markedly increased by effectively decreasing the search space, increasing the relevance and allowing suitable human intervention. The whole searching process complies more with the common human process. The output of the simple-search module is one or more possible products that best satisfy the searching criteria.

4.3 Design transformation

This is the core of the detailed design reuse process. It is at this step that a new design is generated and the user's design intent is realised. As mentioned before, the design transformation is based on the concept of "product family", which means that a new design is achieved through manipulations of an existing product family. All of the available manipulations are addressed next, and the process of the design transformation is self-evident.

Product family creation. When a satisfactory product has been retrieved for reuse based on a user's requirements, the user needs to check whether this product belongs to any existing product families. If it does, the user can generate a new design by adding a member into this family; otherwise, the user needs to first define a new product family, that is, to specify the attributes in a product family definition. This checking mechanism is performed through a set of similarity metrics [17]. At the user's request, all of the features and parameters in the solid model of the retrieved product will be extracted and presented to the user as a dynamic HTML form. The user can choose those features and attributes that may vary for each different member product, and the selections will be sent back to the UG/API server program for processing. As such, a new family definition will be created and set up.

Adding member product. When a product family is available, the user will be prompted with a form to provide all of the desired values for the new design, as shown in Fig. 6. All of these data will be submitted to the UG/API program, and the solid model for the new design is generated based on the variant method. The new design will be stored in the database. The user can instantly view the result from the graphical display on the Web-page.

Editing product family definition. Sometimes, even when a product family is available, the user might want to modify some other features or parameters that are not included in this product family. In this situation, the user can edit the family definition of this product family by choosing more features or parameters and adding them into the definition, as shown in Fig. 7.

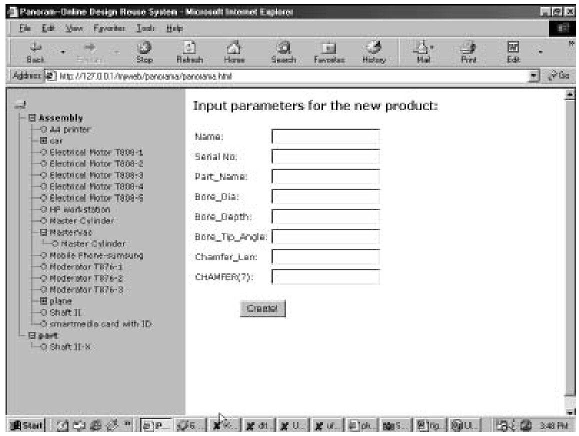


Fig. 6. Interface for adding a new member product

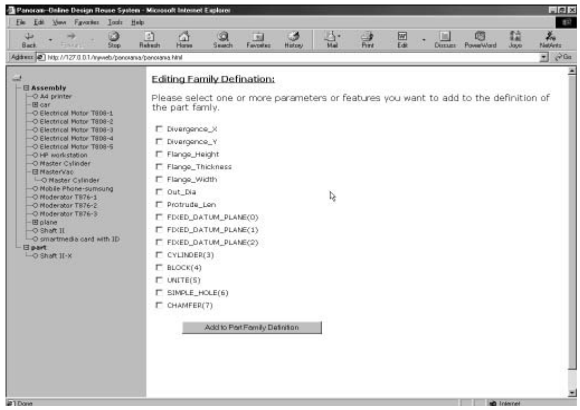


Fig. 7. Interface for editing a family definition

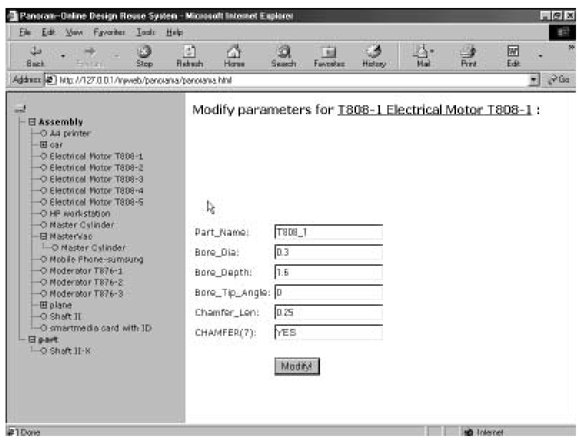


Fig. 8. Interface for editing a member product

Altering existing design data. An existing detailed design can also be modified in this online Web-based environment. For a certain product, all of the family attributes and their corresponding values will be extracted; the user can make alterations in the interface shown in Fig. 8 and submit them, and the solid model of the product will be modified correspondingly.

5 System implementation

In the online Web-based environment that has been developed in this research, the HTTP server program is developed using PHP, and the UG/API server program is developed using the C language based on the UG/Open API on an online UNIX host. The two programs communicate via the Internet socket. MySql is the adopted relational database. All experimental geometrical data are created with the UG solid modeller V15. An Apache server is used for Web publishing. In the prototyping stage, a Blaxxum 3D viewer is used as the embedded viewer of Internet Explorer for the VRML files.

6 Conclusions and future work

Theonline Web-based design reuse system that has been presented in this paper provides a distributed, efficient and low-cost means for detailed design reuse. It reduces the difficulties of common users handling sophisticated CAD systems in detailed design reuse, and makes the existing product data more meaningful and accessible. Another advantage of this online Web-based environment is that for many small and medium enterprises, their products usually fall into several product families, and many of their design tasks can be achieved through modifications of existing designs. Hence, with this online Web-based system, the resource of the CAD system can be shared throughout the enterprises.

This online Web-based design reuse environment forms the basic framework for the development of a comprehensive design reuse system that is capable of supporting concept design and embodiment design reuse. To achieve such a system, more intelligent and robust searching and retrieving mechanisms need to be added. Research is currently being undertaken in this respect and will be addressed in later articles. The future work also includes making the detailed design reuse module more generic by being able to handle various kinds of CAD data formats.

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