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Research on Parameter System and Key Technology of Reverse Engineering

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Abstract: This study puts forward the basic concept about reverse engineering. In the light of the applied target of reverse engineering and current situation of reverse engineering research, the paper presents the concepts about reconstruction parameter, objective prototype parameter and original design parameter in reverse engineering. It points out that the reverse engineering used in manufacture industry should evaluate reversely the original design parameters that are foundation of making new products. According to the applied target of the reverse engineering, the paper puts forward that the implement for reverse engineering is divided into similar design stage and precision design stage and correspondingly manufacture process is divided into the similar manufacture stage and the precision manufacture stage. The goal of the similar design stage is to obtain reconstruction parameters. The goal of the precision design stage is to obtain the original design parameters. The reverse engineering of the precision design stage is used to manufacture the products that must satisfy to assembling demand. The study shows the working model of the reverse engineering system that includes similar stage and precision stage.

Key words: Parameter system, reverse engineering, 3D reconstruction, feature distinction

BASIC CONCEPT OF THE REVERSE ENGINEERING AND ITS USAGE

Basic concept of the reverse engineering: Reverse engineering consists of prototype reversing, soft reversing and image reversing. The prototype reversing in the paper is a process of reconstructing and generating the CAD model and manufacturing starting from an exiting part or prototype.

The design process of reverse engineering is different from conventional design. Conventional design(or correctitude design) process is to design products according to function and usage of products, then to get drawings or CAD model and manufacture products after engineering drawings or CAD model is checked. Reverse engineering starts from an exiting part or a prototype. Firstly the part is digitized (or the part is denotation by point data set), then CAD model is generated. After checking the model, the drawings can be output if necessary and the product is manufactured. (Puntambekar *et al*., 1994).

At a word conventional engineering is starting from engineering drawings then producing associated parts but reverse engineering is starting from an existing part and generating it's engineering drawings and manufacturing that part. That is the meaning of "reverse".

Development and usage of reverse engineering: The copy technology is the developing foundation of reverse engineering that has been used in mechanical manufacturing filed for many years. But the meanings of reverse engineering recently have been expanded.

Objective copy is to produce a part as same as the objective prototype; but reverse engineering is to produce a new part based on modification and redesigning of the objective prototype which not only avoids lost in law but also satisfies the modern social demand. Therefore in design stage reverse engineering must generate the CAD model in order to modify and redesign the prototype but the copy technology does not do it. It is the essential difference between reverse engineering and copy technology.

REVERSE ENGINEEREING'S PARAMETERS

Reverse engineering's parameter system: The result is the product's engineering drawing in the conventional design. The product's engineering drawing is the gist to manufacture the product. A parameter embodied in the product's engineering drawing is determined by designer according to some design ideas and principle. It is only one that appears in conventional design. The result is to reconstruct CAD model in reverse engineering. The parameter embodied in CAD model is determined by various factors of the parameter embodied in prototype, measuring precision, surface fitting precision, etc. There are many parameters in reverse engineering but not only one. For illuminating it, the basic concepts of three kinds

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of particular parameters in reverse engineering, objective prototype parameter, reconstruction parameter and original design parameter, are introduced firstly.

The result of reverse engineering is CAD model. Obviously the CAD model has a lot of parameters (mainly geometric parameters). These parameters are obtained by fitting calculation of point data which were given by measuring and embodied on the CAD model. So this kind of parameter is called as the reconstruction parameter. The part or prototype which is operated in reverse engineering has its own shape and parameters. The parameter embodied on prototype is called as objective prototype parameter. While the part or prototype is manufactured the parameters in engineering drawings must be gist. The parameter embodied in designing drawings of producing part or prototype is called as original design parameter. This is original one for manufacturing part or prototype. These three kind of parameters consist of the parameter system of reserve engineering.

Reconstruction parameter is obtained by reverse engineering, so it is knowable and explicit. Usually reverse engineering does not measure prototype directly, so objective prototype parameter is unknowable. Original parameter is obviously unknowable. Objective prototype parameter and original design parameter are implicit. The parameters' implicit property keeps researches from noticing and studying of them.

Errors analyses of reverse engineering: Now reverse engineering manufactures product by using knowable model parameter reconstructed, in other word using reconstruction parameter. In many cases reverse engineering's purpose is that the new product replaces the prototype. The new product will work in prototype's circumstance. Here if the new product is manufactured by reconstruction parameter there must exist errors. Now the error between reconstruction parameter (to manufacture product) and original design parameter (to manufacture prototype) is compared. Let the error is reconstructing error, symbolized by $\square_r$.

It is unavoidable to produce errors in the calculation which is named as calculating error Δ_c. The measurement must have errors while measuring prototype which is named as measuring error Δ_m. The prototype itself has errors. One of the error is produced while a prototype is produced which named as producing error Δ_p. Another error is formed while the prototype is worked because of wearing out and dilapidation, named as wearing error Δ_w. Reconstructing error consists of these errors. It can be expressed:

$$\Delta r = f(\Delta c+\Delta m+\Delta p+\Delta w)$$

Generally, reconstructing error can be considered as:

$$\Delta_r = \sqrt{\Delta_c^2+\Delta_m^2+\Delta_p^2+\Delta_w^2}$$

In view of only discussing copy prototype the product that is manufactured in reverse engineering replaces prototype and works under the prototype's circumstance. Prototype is manufactured according to objective prototype parameter and product is manufactured according to original design parameter. According to the aforementioned analyses there exits reconstructing errors Δ_r between objective prototype parameter and original design parameter. So in many cases it will be shortage of demand that product is manufactured by objective prototype parameter and set under the prototype's circumstance in order to replace prototype to work. In other word because of existing reconstructing error product will be wasted. The case must appears when a strict match of a prototype with other parts is required. In order to improve precision reverse engineering takes a lot of steps, such as improving measure and calculation precision. The steps are necessary but can not resolve the ultimate question completely. Because they can reduce measuring error Δ_m and calculation error Δ_c, cannot reduce producing error Δ_p and wearing error Δ_w. The steps can at best make reconstruction parameter closer to objective prototype parameter but cannot obtain original design parameter.

Reverse engineering's applied target and engineering actualization: Reverse engineering's applied target can be divided into (1) Copy prototype; (2) Modifying prototype design and manufacturing new product; (3) Inspecting manufacturing quality. The former two cases are the main targets. Copy prototype is divided into two cases. One is that there is no special demand on prototype's circumstance and prototype is a sculpture or plastic part with elasticity. Another case is that prototype's circumstance is demanded especially and prototype matches other parts precisely which is ubiquitous in mechanical industry. In the former case prototype's geometric surface is merely reconstructed. It demands shape resemblance but does not demand precision. Then the design is named resemblance design and the manufacturing is named resemblance manufacturing. In the latter case it is necessary that the finished part is manufactured according to original design parameter in reverse engineering because of its using target. So original design parameter must be obtained in design stage in reverse engineering. The work that seeks for original design parameter is named original design

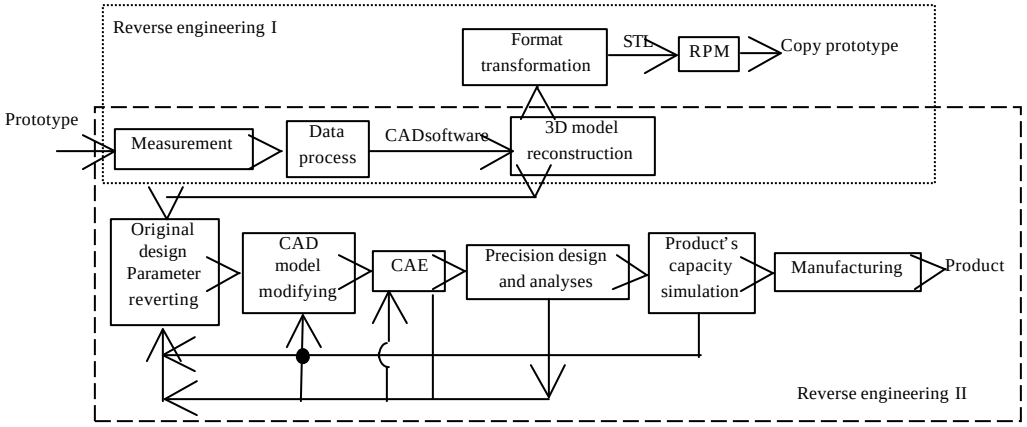

Fig. 1: Working process of reverse engineering system

parameter reverting. Here reverse design is precision design to a certain demand and reverse manufacturing is precision manufacturing.

According to the applied targets reverse engineering is divided into two stages. The working process is shown in Fig. 1.

In the superposition of reserve engineering I and II, reverse engineering II has some special characters, such as there are enormous data to be handled and it needs to use special arithmetic to generate CAD model and is able to reconstruct a prototype of shapes.

KEY TECHNOLOGY OF REVERSE ENGINEERING

The part measuring, 3D model reconstructing and original design parameter reverting are the key technology of reverse engineering (Luan *et al*., 2003; Wang and Wu, 2007). The methods, processes and ideas to solve the key technology are shown by introduction the 3D model reconstructing system developed by the authors.

Part measuring: The part measuring stands for measuring geometrical coordinates of surfaces of the part or prototype by the measuring equipment. Presently the measuring methods that are used in industry include CMM (coordinate measuring machines), laser beam scanning, industrial computed tomography and layer-layer cutting image (Menq and Chen, 1996; Wang and Li, 2002). CMM and laser beam scanning are utilized for measuring external part geometry; industrial computed tomography and layer-layer cutting image are utilized for measuring complex internal geometry. Although industrial computed tomography is more expensive and less precision it is only method that measures complex internal geometry of no spare and duplicates the part with no destruction. Layer-layer cutting image is a slicing measuring technology recently developed. It cuts the part layer by layer in teeny thickness and takes a photograph of the slicing layer. It is the highest precise slicing technology now. But it destroys the part which is its fatal defect.

3D model reconstructing process based objective prototype: The process generating CAD model or reconstructing prototype is shown in Fig. 2.

3D model reconstructing process is divided into three stages. The stage 1 is data management. Firstly the system that was developed by the authors filters out noise from original slicing data (or slicing image). The system are with a filter function library including a lot of filter function. The user can select associated functions for various image property to find the better result. Then the system extracts borders after filtering image. The system uses the effective algorithm to extract borders for slicing data of object prototype in reverse engineering. While extracting borders the system's parameters can be modified by man-machine conversation to eliminate futile data such as air holes and chips. After extracting borders closed rings or data rings are formed out.

The stage 2 is the feature recognition. The system manages firstly data rings. The data rings that belong to the same feature are extracted and construct entity rings of the feature. The management process actually is a process of matching data rings. The system mates data rings according to the shape, size and space position of data rings and generates entity rings. Then the system identifies the feature of entity rings by automatic or man-machine conversation, generates the named feature

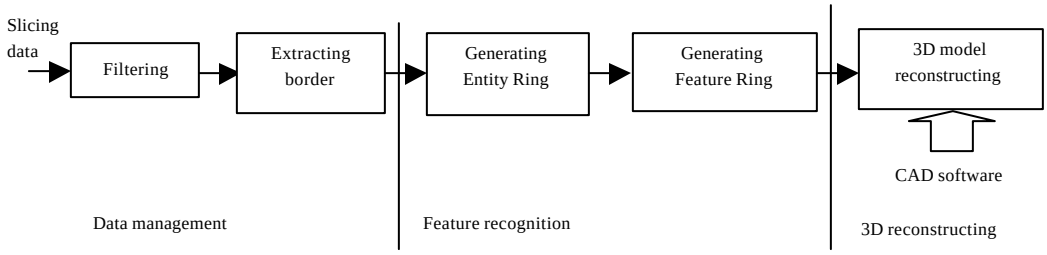

Fig. 2: 3D model reconstruction process

rings. The system identifies feature in three administrative levels: Feature lines (line, arc, circle, free curve), feature surfaces (plane, cylinder, free-form surface) and feature cubes (columniation cubic, free-form surface cubic). With man-machine conversation the relative identification can be used so that the result identified by man must be verified by the system to prove the identified feature; or the absolute identification can be used so that the result identified by man accepted directly no proof.

The last stage is 3D model reconstructing on the support of the selected CAD modeling software. Therefore the system must provide interfaces to CAD software. The system is supported by SolidWorks.

Original design parameter reverting: Original design parameter reverting is a particular problem for discussion in reverse engineering and a new subject. We do some useful researches and have obtain some valuable experience in the field by using Artificial Intelligence, the Mathematical Statistics Theory and the Precision Design Theory (Li *et al*., 1999). But a great number of research must be done for practicality.

CONCLUSION

Presently it is disadvantages and regrets of the reverse engineering researches that the research of the reverse engineering is limited to 3D reconstruction of CAD models in the world, the reconstruction parameter is regarded as the original parameter of manufacturing products and the study is a sort of "resemblance manufacture" but not "precision manufacture" . In view of such situation, the authors consider that the research of the reverse engineering is in the elementary phase of reverse engineering I which is called by the authors. While the goal of the reverse engineering II is to give full play to the characteristics, not only to achieve assimilation and absorption of the product's design and manufacturing technology by the prototype but also to modify and redesign the prototype, so as to realize the objective of an innovation. The synthetic use of the Artificial Intelligence, the Mathematical Statistics Theory and the Precision Design Theory forms a particular technology of design parameter reductive that effectively solves the problem of design parameter reductive which is the development direction of reverse engineering.

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