Research on Reverse Engineering's Parameter System

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Abstract This paper analyses the current situation of reverse engineering. It points out that the reverse engineering used in manufacture industry obtains measuring data from the objective prototypes, adopts appropriate data processing methods according to obtaining data methods and types and accomplishes the 3D reconstruction and reappearance of the objective prototype. Because of kinds of facts, such as, manufacturing errors, measuring errors, and so on, there is obvious gap between manufacturing data and prototype parameters, so manufacturing data may be useless in some cases. In view of exiting situation, the paper puts forward that there is a parameter system that includes the objective prototype parameters, reconstruction parameters and original design parameters in the reverse engineering. The paper elaborates that the certain parameters must be obtained according to the given demand in a given situation and considers that the reverse engineering used in manufacture industry should evaluate reversely the original design parameters that are foundation of making objective prototype and new products. On this basis, this paper divides the project implementation of reverse engineering into I, II stages and gives the corresponding working process. The working process underlines the "innovation" function of reverse engineering, widens the application range of reverse engineering.

Keywords CAD model • Innovation design • Parameter system • Reverse engineering

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1 Introduction

The modern meaning of reverse engineering is the integrated applications of the integrated system in computer aided measuring, computer aided geometric modeling, computer aided design and computer dynamic simulation, computer aided manufacturing (Abella et al. 1994; Saeid Motavalli and Bopaya Bidanda 1994; Puntambekar et al. 1994; Daschbach et al. 1995; Liang-Chia Chen and Lin 1997). Analysis the requirements of the reverse engineering technology in modern industrial, and study on the reverse engineering basic theory and its engineering actualizing undoubtedly is one of the contents of reverse engineering.

Reverse engineering is relative to convention engineering (also called forward engineering). The design process of reverse engineering (reverse design) is completely different from the design process of convention engineering (forward design). Forward design has four stages: production decision-making stage, project decision-making stage, structure of decision-making stage and processing decision-making stage.

For reverse engineering, there is also a process of recognition social demands and decision-making and planning. Once make decisions in production making-decision stage, it is different from forward design that start to design from the planning making-decision, reverse design is from existing objective prototype or a part to begin the next stage design work. Reverse design need to understand the principle design project of objective prototype through data acquisition and 3D reconstruction process (Luan Yi-guo et al. 2003; Wang Ying-hui and Wu Wei-yong 2007; Li and Li 2010), and lays the foundation for copy prototype or redesign prototype of the next stage. After reconstruct 3D solid of the prototype, according to the recognition for social demands and product planning, the prototype can be copied, or according to the market requirements, to carry on redesign on the basis of the prototype, and achieve “innovation”. Moreover, since reverse engineering can carry on computer aided process simulation, performance simulation, assembly and manufacturing process simulation for 3D model to be reconstructed and modified, it basically does not need sample manufacturing link, ensure manufacturing success one time. The working stage of reverse design as follows: 3D reconstruction stage, principle project analysis stage, function analysis stage, innovation design stage.

2 Reverse Engineering’s Application Target

The object prototype of reverse may be the whole machine, or an assembly (component), may also be a single part. And the purpose of reverse engineering, so far, is nothing more than two cases: (1) making the product as same as the prototype, namely copy prototype; (2) on the prototype basis, through the modification or redesign, creating new product. And from the point of view of products using environment, also is no more than two cases: (1) the product has no special requirements to work environment, that is the product (regardless of whole

machine, components, or single part) does not occur special coupling assembly relationship with other parts that are outside of reverse object, or the connection assembly relationship easy to realize. Such as art sculpture, in addition to the shape cooperation requirements with the base, it does not come in contact with other parts. This kind of prototype is called as solitary part. (2) products that are produced in the reverse engineering have high assembly requirements with the other parts that are outside of reverse objects, and the assembly requirements can only use strictly fit tolerance to ensure that, this is the most common in the machinery manufacturing industry. This kind of prototype is called as mating parts.

Generally speaking, for the modification of prototype, the purposes have two: (1) to modify the prototype due to performance reasons. The performance mentioned here, both may be the use performance of the product, also may be the installation performance of the product. The use performance refers to the product must meet certain requirements of the use aspect, and the installation performance refers to the product must fit properly with the other parts that except the prototype. At this time, it is not only to modify the prototype shape, and also must ensure that the modified prototype meet certain requirements in terms of size, precision, performance, and so on. As for the guarantee of the installation performance of all parts within the prototypes, after inverse analysis the prototype function, working conditions, mating requirements, it can be given by way of forward design, so this paper does not specifically discuss. (2) from the ergonomics requirements to modify the prototype. Which requires product modeling is nice, all surfaces are smooth and have comfortable looking sense and touching sense. At this time the modifications is mainly to modify the shape.

According to the application purposes, using environment and modification purpose of reverse engineering, the application of reverse engineering can be divided into two types: (1) for the model after reconstruction and the product to be manufactured do not have higher precision requirements, such as the imitation and appropriate modified of isolated parts, so they are all called as the simple reconstruction and imitation of prototype. (2) for the model after reconstruction and the product to be manufactured have higher precision requirements, such as the imitation and modification of matching parts, to modify the performance of isolated parts, so they are all called as the precise reconstruction of the prototype and redesign based on prototype.

Based on the above analysis, this paper considers that the application targets of reverse engineering are as follow:

Application target 1: simple reconstruction and imitation for prototype.
Application target 2: accurate reconstruction for prototype and redesign based on prototype.

Application target 1 is the short-term goal of reverse engineering, it also is currently research focus of reverse engineering. Rapid prototyping (RP) is one of the methods to achieve application target 1. The application target 2 is the long-term goal of reverse engineering, its focus is on innovation.

3 Reverse Engineering's Parameter System

3.1 Special Requirements of Application Target 2 for Reverse Engineering Technology

One of the requirements of redesign of reverse engineering based on the prototype is the new products to be manufactured by reverse engineering must have correct cooperate relations with the other parts, in accordance with the current common practice of reverse engineering, only to find the prototype three-dimensional model and parameters could not meet this requirement.

As shown in Fig. 1, if the right end of the part 1 is fitted in the internal hole of the part 2, and according to its use requirements, the size D of combination portion of the part 1 and part 2 should be $\phi 22^{+0.021}_{+0.008}$. Set part 1 has processed good later, after measuring, the actual size is Ø22.01, meet the demand, working properly after installation. Still suppose, due to some special reasons, need to use inverse method to process a new part 1, and installation and working together with the original part 2.

Because there must be certain error in data acquisition and processing, surface modeling, three-dimensional solid reconstruction, the parameter D obtained by reverse engineering system cannot be precisely parameter Ø22.01 of original part 1. Suppose the obtained size is Ø22.008, for manufacturing the new part 1, must be given the tolerance value of the size. When only have one actual measured value, the existing practice of reverse engineering system, the value is used as a mid-value of tolerance (Liu and Huang 1992). According to this principle, and in accordance with inverse analysis working performance of part 1 and part 2, after determining the cooperate and precision grade between the both, still follow the current practice of reverse engineering system, according to the size series standard to confirm the basic size and its tolerance zone of part 1, finally determine the size D is $\phi 22^{+0.014}_{+0.001}$.

Suppose the size D of the new part that has machined is Ø 22.002, meets the requirements. Suppose the size that the original part 2 corresponds to the size D does not change (although this is not possible). Take new part 1 to mount on work

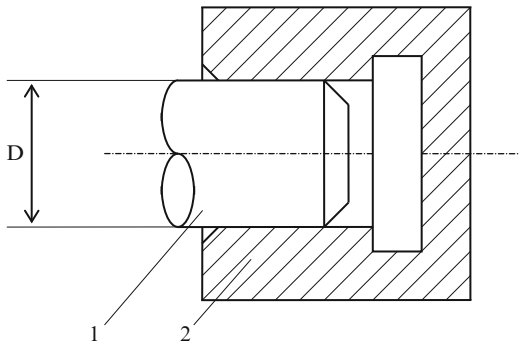

Fig. 1 Application example of reverse engineering

place of the original part 1, the size D is matched part 2. Obviously, owing to the size D of the new part 1 is Ø 22.002, so the cooperation nature of the new part 1 with part 2 not is the cooperation nature of the original part 1 with part 2. The new part 1 does not work normally as like the original part 1. The part 1 becomes a waste. This product of machining meet the requirements becomes a waste, the primary reason is the basic size and tolerance of the new part 1 that is given by reverse engineering system gives is wrong.

The current reverse engineering research considers that the parameters to be solved out by reverse engineering are the real parameters of the prototype, and use them as the basis of manufacturing new products. Above example illustrates, using this parameter as the basis of manufacturing product, when the prototype has matching requirement with other parts, it will appear waste, so it is wrong. That is to say, at present, the research level of reverse engineering that use the reverse parameters as the solution target, can not realize the application target 2.

3.2 Reverse Engineering's Parameter System

In some cases, why reverse engineering cannot use the reverse parameters as the basis of manufacturing new products? The parameters to be solved out by reverse weather or not are real parameters of prototype? In the above example, the parameter D $\phi 22^{+0.021}_{+0.008}$ which is the basis of manufacture prototype (original part 1) has what function in reverse engineering? The parameter D $\phi 22^{+0.014}_{+0.001}$ which is the basis of manufacture product (new part 1) has what function? From the above example, it is not difficult to produce these doubts.

To solve these doubts, the first to analyze the unique parameter system in reverse engineering.

The result of the conventional design is the product's engineering drawing. The product's engineering drawing is the gist to manufacture the product. The design parameter embodied in the product's engineering drawing is determined by designer according to some design ideas and principle. It is a unique parameter that appears in conventional design. After the product has manufactured, the product itself possesses the parameter. Using direct or indirect measurements, it can determine the product's parameter. If the parameter fits with the design parameter, the product is a qualified product. The result of reverse design is the CAD model to be reconstructed, the parameter embodied in CAD model is determined by various factors of the parameter embodied in prototype, part digitizing precision, measuring precision, surface fitting calculating precision, and so on. Owing there are part digitizing and fitting calculating, the reverse parameter embodied in CAD model not is already the parameter of the prototype itself. In fact, there are many parameters in reverse design but not only one. In reverse engineering there are three kinds of particular parameters that have a decisive influence to the result of reverse engineering, objective prototype parameter, reconstruction parameter and original design parameter.

The result of reverse engineering is CAD model of reconstruction prototype. 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.

The original design parameter is the basis of manufacturing objective prototype, and is the foundation to form objective prototype and hence to form objective prototype parameter. The objective prototype through digitizing, reconstruction calculating produces the reconstruction CAD model, so the objective prototype parameter is the foundation to form the reconstruction CAD model and hence to form the reconstruction parameter. This is the causal relationship among these three parameters. Therefore, it is wrong that the reverse engineering research takes the reconstruction parameter as the objective prototype parameter. Because it is different with the forward engineering which using direct or indirect method determine the prototype parameters, the various data collection methods in reverse engineering, such as CMM (coordinate measuring machines), laser beam scanning, industrial computed tomography and layer-layer cutting image, etc., (Menq and Chen 1996; Kochan 1995; Zhang Chang et al. 1997; Wang Ying-hui and Li Quan-qing 2002; Wang Ying-hui et al. 2003; Li Quan-qing and Li Ming 2009) obtain a serious of dot coordinate on the prototype surface, but not is the parameters of the prototype surface. Therefore, a variety of data collection methods can not directly or indirectly measure the prototype surface, only after fitting calculation, it can know the surface parameters of the prototype (actually they are the surface parameters of reconstructed CAD model). This is the reason that the data collection is called as “Digitizing the part”, instead of “Measure”. Because there are the digitizing the part and the fitting calculation, the parameters to be obtained by reverse engineering are the reconstruction parameter, rather than the prototype parameter. In reverse engineering, the reconstruction parameter 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. In above example, $\phi 22^{+0.021}_{+0.008}$ is Original parameter, Ø 22.008 is reconstruction parameter, Ø 22.01 is Objective prototype parameter.

Establishing reverse engineering parameter system, for analyzing the error of reverse engineering, correctly determining the solving target, realizing the innovation function of reverse engineering, has a very important significance.

4 Reverse Engineering's Engineering Actualization

Reverse engineering's application target, for the reverse engineering system function, the results requirement is different. Application target 1 is that there is no special demand on prototype's circumstance, the only demand is to reverse CAD model of prototype during the design stage, simply copy prototype during the manufacturing stage, or manufacture prototype to be have. In this case, prototype's geometric surface is merely reconstructed. It demands shape resemblance but does not demand precision. Application target 2 is that prototype's circumstance is demanded especially, and prototype matches other parts precisely, which is ubiquitous in mechanical industry. 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 parameter reverting. Here reverse design is precision design to meet a certain demand, and reverse manufacturing is precision manufacturing.

According to the reverse engineering application target, reverse engineering can be divided into I and II stages. Reverse engineering I is to realize application target 1 stage, reverse engineering II is to realize application target 2 stage. The basic concept and the working process of the system are described in Fig. 2.

5 Conclusion

The characteristics and innovations of this paper are:

Through analysis the application targets of reverse engineering, it puts forward the concept of original design parameter, reconstruction parameter and objective

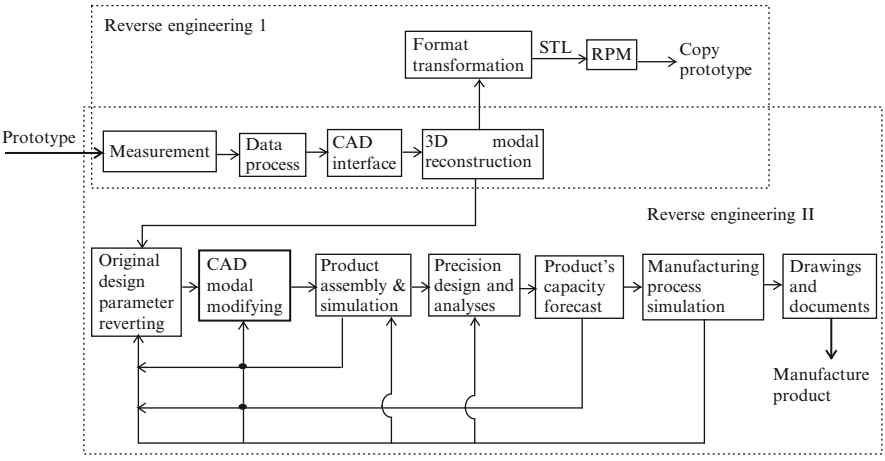

Fig. 2 The process of reverse engineering system

prototype parameter, it has created the unique parameter system of reverse engineering. Then it points out that in most cases of the mechanical field, it should reversely seek out original design parameter that is used by manufacturing prototype, and takes this as the basis of manufacturing new product.

On the basis of analysis the structure of reverse engineering system, the engineering actualization of reverse engineering is divided I and II stages, and has given their working process. The II stage of reverse engineering embodies the "innovation" function of reverse engineering, it has widened the application range of reverse engineering.

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