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Serial 3D model reconstruction for machining evolution of rotational parts by merging semantic and graphic process planning information

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ABSTRACT

The manufacturing of a mechanical part is a dynamic evolution process from a raw workpiece to the final part, in which the generation of serial 3D models reflecting the changes on geometric shapes is especially critical to digital manufacturing. In this paper, an approach driven by the process planning course, the machining semantics and the machining geometry to reconstruct incrementally the serial 3D models for rotational part's dynamic evolution is proposed. The two major techniques involved are: (1) extraction of machining semantics based on process planning language understanding; (2) 3D reconstruction from 2D procedure working drawings guided by machining semantics and visualization for the reconstructed series of 3D models. Compared with the conventional 3D reconstruction methods, this approach introduced the process planning course and relevant information to implement a dynamic, incremental and knowledge-based reconstruction which can greatly reduce the efforts in reconstruction and extend the collection of geometric shapes to be reconstructed.

1. Introduction

The manufacturing of mechanical parts is a dynamic evolution process from a raw material to the final part. In this process, some changes are constantly generated on shape, function and value. With the development of digital manufacturing technology, it is highly necessary to construct the serial 3D models in relative to the part's different manufacturing stages. The benefits of this kind of serial 3D models can be manifested on the following aspects: (1) Revealing process planning intentions. Because a part's dynamic evolution process in geometric shape from raw material to final part is a visualized demonstration for its process planning intentions, it would be useful in the discovery, extraction, re-use and inheritance for process planning knowledge. (2) Extraction of machining features. Traditional methods extract the machining features directly from CAD model without achieving satisfactory results [1]. Since the manufacturing process continually generates the new machining features (hole, groove and chamfer for instance), if we can construct the serial 3D models for different manufacturing stages, the machining features would be conveniently extracted in a natural way. (3) Reconstruction of part's 3D CAD models. As the final element in above-mentioned series of part's 3D models is corresponding with its design model, the problem to generate 3D CAD models for existing 2D-based part design results can be resolved by using this approach. (4) Generation of 3D working procedure models. The 3D working procedure models will be very useful for the complex part's digital manufacturing such as NC programming, inspection, machining sequence verification, and 3D fixture design, etc. With 3D medial models, we can easily obtain the expected 3D working procedure models as they just correspond to some medial elements of the series.

Building the serial 3D models for different machining stages in a rapid and efficient way is a challenging problem. Conventional methods for 3D model reconstruction from 2D engineering drawings have been proven to be difficult [2]. In this paper, we propose a new approach to deal with this problem. The general idea can be explained as follows: from the point of view of dynamic process planning course by utilizing the achievement of CAPP employment, we can combine the natural language understanding with engineering drawing interpretation to get the series of part's 3D models for dynamic machining process. The 3D reconstruction from 2D working procedure drawings will be guided by process planning describing languages which contain the valuable machining semantics. Through intelligent reasoning for the evolving process in geometric shape from raw material to final part, we can incrementally reconstruct the series of 3D models generated in part's different machining stages.

It is worthwhile to differentiate 3D working procedure models from 3D design models (i.e. 3D CAD models). 3D working procedure models are a series of geometric models which reflect the changes applied to the raw workpiece in shape and dimension

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during the machining process. While the 3D design model corresponds to the final state after the manufacturing is finished. For a complicated part, it will be usually necessary to add some auxiliary structures to improve its manufacturability (e.g. false bosses designed for aero-engine).

The rest of this paper is organized as follows: Section 2 reviews the existing research works relevant respectively to 3D reconstruction from 2D orthographic views, natural language understanding and computer aided process planning; Section 3 describes the basic principles and proves the feasibility of our approach; Section 4 presents the key techniques used in the reconstruction process by merging semantic and graphic process planning information; Section 5 shows a case of implementation; Finally, some conclusions are given in Section 6.

2. Related work

Up to now, great deals of research works have been done on 3D reconstruction from 2D orthographic views. The approaches proposed can be classified into the following four categories: (1) Bottom-up approaches [2,3] using respectively wire-frame, surface and B-rep model. The 3D solid is formed after constructing wire-frame model according to project and anti-project to describe the 3D reconstruction problem. (2) Top-down approaches which utilize the natural language processing technology to understand the text annotations appeared on engineering drawings and then extract project information to reconstruct 3D solids. Dori and Weiss [4] used a semantic analysis method to interpret the functions for graphic elements in engineering drawing and to obtain a conception model composed by graphic elements, dimension sets and text annotations; Lu et al. [5] proposed some rules to classify the graphic elements in 2D orthographic views based on engineering semantic and generated a synthetic network composed by graphic elements and dimensions. (3) Model-guided approaches [6,7] which extract the basic graphic solids by pattern matching directly from 2D orthographic engineering drawings in virtue of CSG modeling principle and generate CSG tree, and 3D solid model can be finally achieved. (4) Reconstruction approaches based on expert system [8,9]. This kind of approaches introduced the techniques of artificial intelligence and expert system to establish relevant knowledge base, rational mechanism and search strategies to support reconstructing process. Therefore, the drawbacks caused by purely applying solid geometry and drawing theory can be avoided.

Generally speaking, two research trends are existed currently for 3D reconstruction from 2D orthographic engineering drawings: one is the combination of multiple approaches especially by introducing expert system, case-based reasoning, constraint satisfaction, fuzzy logic and neural network technologies to improve the existing algorithms; another is the mining of engineering semantics from the engineering drawing itself to implement 2D drawing view interpretation and 3D reconstruction on a higher level.

The major difficulties and challenges for 3D reconstruction from 2D orthographic views can be summarized as follows: (1) The interpretation for 2D engineering views is a complex and theory-weak process, it is difficult to give an accurate and formalized description, and the efficient combination for knowledge description, rational and their graphic presentation and calculation is also difficult to be realized [10]. (2) The 3D reconstruction concerns the transformation of geometric and topologic information from 2D orthographic views to 3D solid. It is difficult to find a rigorous mathematic model to constrain this transforming process. And the existing techniques are unable to well solve such two problems: one is the extension of shape covering domain and another is how to decrease the algorithms' time complexity [9]. (3) Introducing engineering semantics to assist the reconstruction process is an effective strategy to reduce the difficulty on reconstruction. However, the relevant existing algorithms address primarily the engineering drawing itself to extract engineering semantics. When the engineering drawing becomes more complex, it is difficult to extract sufficient engineering semantics and leads to this method invalid. (4) Only geometric shape information and limited semantics information are focused by conventional 3D reconstructing approaches. Further engineering semantics information as design and machining features is absent and it makes this technique difficult to meet the requirements of integrated applications for CAD/CAPP/CAM systems.

Another technology concerned in our research is the natural language understanding. From the first generation of the machine translation system based on mainly lexical transformation, occurred in the 1950s. A number of techniques have been proposed such as Chomsky's transformational generative grammar, Quillian's semantic network theory, Fillmore's Case Grammar and Kaplan and Bresnan's Lexical Function Grammar, Schank's Conceptual Dependency theory, corpus-based approaches, and the theory of Hierarchical Network of Concepts and so on [11]. In general, there are great challenges on natural language understanding for universal domains due to the following reasons [11]: firstly, the natural language is an extremely complex symbol system; secondly, the great number of uncertain properties exist in almost all levels for natural language understanding; thirdly, the natural language is not a fixed language; and finally, as tool for communicating with human beings, the natural language faces also the problem of 'knowledge representation' as in artificial intelligence domain. However, the natural language understanding for specific domains has some favorable advantages as the applications of a number of special vocabularies and the decreasing of signifier items can reduce to a great extent the generation of heterogeneous meanings. So it is certain that the natural language understanding in specific domains can be more easily implemented and more satisfactory understanding results can be acquired [11,12].

In the domain of process planning for mechanical part's manufacturing, CAPP technologies and systems have been extensively used in manufacturing companies [13]. However, the existing CAPP systems are generally based on 2D CAD and they are obviously lagged and non-compatible with the development and applications of 3D CAD technologies, which makes them difficult to support more advanced application scenarios. With the development of digital manufacturing technology, 3D working procedure modeling for complicated parts is increasingly required by aeronautical, astronautic, shipping and automobile manufacturing industries. Actually, one alternative solution is to adopt interactive modeling approach using CAD systems, but it is generally less efficient and consumes great deal of repetitive work. Some scholars have studied various reasoning approaches to get the working procedure models from 3D CAD models of workpieces [14]. The implementation of this reasoning strategy is very difficult as it greatly depends on human beings' experience and knowledge and a number of human–machine interactions are needed. So it is necessary to develop more advanced 3D modeling technologies oriented to the different machining stages for a mechanical part.

In summary, for the technology of 3D reconstruction from 2D orthographic views from its appearance up to now, the breakthroughs and practical progresses are absent and this technology is still difficult to put into engineering applications [10]. On considering the applying environment of engineering drawings in digital manufacturing and CAPP's development trend, this paper proposed a new reconstructing strategy by merging semantic and graphic process planning information to generate the serial