New method of 3D reconstruction from mechanical engineering drawings based on engineering semantics understanding

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Abstract

3D reconstruction from mechanical engineering drawings is a method of automatic generating 3D solid models. For the purpose of enhancing the practicability of the technique of 3D reconstruction, this paper presents a new reconstruction method based on engineering semantics understanding. Its principle is similar to the method of figuration analysis used by experienced engineers. The characteristic of the new method is as follows: First, engineering semantics understanding is used to accelerate feature recognition of components or primitives. Second, a mechanism of supposing and ascertaining for 3D reconstruction is set up and views testing are adopted to validate the result solid. Third, integrated reconstruction techniques are used to enlarge the figuration domain of reconstructed objects. Last, case-based reasoning is used to establish a self-learning mechanism of primitive feature recognition. It is implemented at the desktop of AutoCAD 2004 by using Object ARX 2002 and VC++6.0. Experimental results show that some improvements are gained by using the new algorithm on the aspect of utility scope and processing speed of reconstruction.

1. INTRODUCTION

3D reconstruction from mechanical engineering drawings is a method of automatic constructing 3D solid objects. It is the pivot part of the system converting 2D paper-based engineering drawings into 3D CAD model files. It can provide 3D CAD model for application of advanced manufacturing technology such as CAM, CAPP, CAE, PDM, CIMS, VM, RP&M, *etc*. Its application can not only save tremendous time and labor but also broaden the domain of computer vision from perspective images understanding to projective graphics understanding.

Idesawa first presented this issue in his paper "A system to generate a solid figure from three view" in 1973 [1]. Various algorithms starting from three views have been published in the literature since then. Among them, boundary representations (B-rep), constructive solid geometry (CSG) and the approach-based algorithm are typical algorithms and most of other algorithms are improvements of the typical ones [2].

The B-rep algorithm is a bottom-up approach. 3D solid objects by B-rep are constructed direct by 2D information in the following order of precedence: vertex→edge→loop→face→solid. Module A among fig. 1 shows the framework of the B-rep algorithm. Main steps of the B-Rep algorithm [3] are as follows: a wire-frame that is composed of 3D vertices and 3D edges is first recognized from the input orthographic views. Then, candidate faces are found from all these 3D edges. Pseudo elements are deleted by certain criteria and all true faces are assembled to form a goal solid.

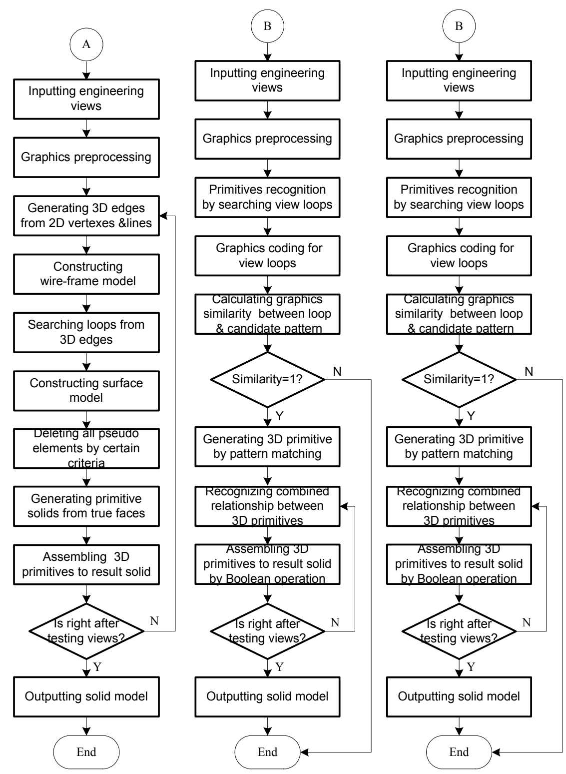

Figure 1: Framework graph of three typical algorithms based on geometrical reconstruction

(Module A—the B-Rep algorithm, Module B—the CSG algorithm, Module C—the approach algorithm.)

The CSG algorithm is a top-down approach and is based on volume decomposition-synthesis. As shown as in module B among fig. 1, it [4] assumes that each 3D object can be built from certain primitives in a hierarchical manner. It selects a 2D loop as a base and generates the 3D primitives by matching their corresponding 2D patterns in each view, then assembles 3D primitives to form a goal solid. The main idea is as follows: any solid with complex figuration can be combined with a series of pre-defined 3D primitives such as box, sphere, cylinder, cone, wedge, torus, pyramid, *etc*. All 3D feature and three-view projective features of pre-defined primitives are described as a series of patterns and constructed models. In the reconstruction process, it is first to extract primitive loops from each view, then to match patterns by using the technique of structure pattern recognition. If the loops searched from 3 views match exactly the pre-defined 3-view patterns of primitive, 3D primitive can be direct generated according to its pre-defined 3D pattern. Otherwise, there is no solution.

The approach algorithm [5] is similar to cutting mechanical part. Module C among fig. 3 shows its main steps. First, a reference solid is generated by translational–sweeping and Boolean intersection operation. Then, the difference solid is reconstructed by comparing the views between the reference solid and the result solid. Finally, by subtracting the difference solid from the reference solid one by one and testing the residual solid by views, the goal solid can be finally obtained.

Although 3D reconstruction from 2D orthographic views has been studied for over three decades, the present algorithms are still far from the desired goal of a general solution and practical application [6]. The main problems of geometric reconstruction are as follows: 1) Reconstructed objects are usually three orthographic views, in which there are no centerlines, no dimension, no cutaway views, no sectional views and no auxiliary views and so on. 2) For B-Rep, its reconstruction efficiency is low and it is easy to generate pathological cases; For CSG, it is difficult to deal with complex figuration because limited pre-defined primitives patterns restrict its applicability; For the approach-based algorithm, there are a great deal of operations and complicated calculation in 3D space. 3) Using single reconstruction technique leads to limited figuration domain of reconstructed objects. 4) Present algorithms of primitive feature recognition are difficult to deal with intersection and complex primitive features.

Researchers think limits of traditional algorithms based on geometric reconstruction cause less progress on 3D reconstruction research. In order to solve existing problems and seek a new breakthrough, they attempt to use the technique of engineering semantics understanding to recognize primitive feature. In 1984, Yashiura [7] first uses the information conveyed by dimension annotation to recognize primitives. In 1992, Joseph [8] makes feature recognition easier by analyzing the semantics of sectional views. In China, Lu [9] first uses the semantics information conveyed by semi-section or full section views to reconstruct 3D solid. In order to enhance further the practical utility of 3D reconstruction, we take practical mechanical engineering drawings as reconstructed objects and present a new method based on engineering semantics understanding.

2. NEW METHOD OF 3D RECONSTRUCTION FROM MACHANICAL ENGINEERING DRAWINGS BASED ON ENGINEERING SEMANTICS UNDERSTANDING

The key problem of engineering drawings understanding is how to recovery the losing information of geometry and topology at the projective depth direction. Experienced engineers often understand projections by the method of figuration analysis. Main steps of the method are as follows: 1) A complex solid is divided into parts by decomposing view loops. 2) Corresponding loops selected from three views are validated their coherence according to rules of orthographic projection; 3) Corresponding 3D model are generated from typical patterns according to view loops and multiple interpretations are eliminated by views testing.

2.1 Main idea and whole framework of the new method

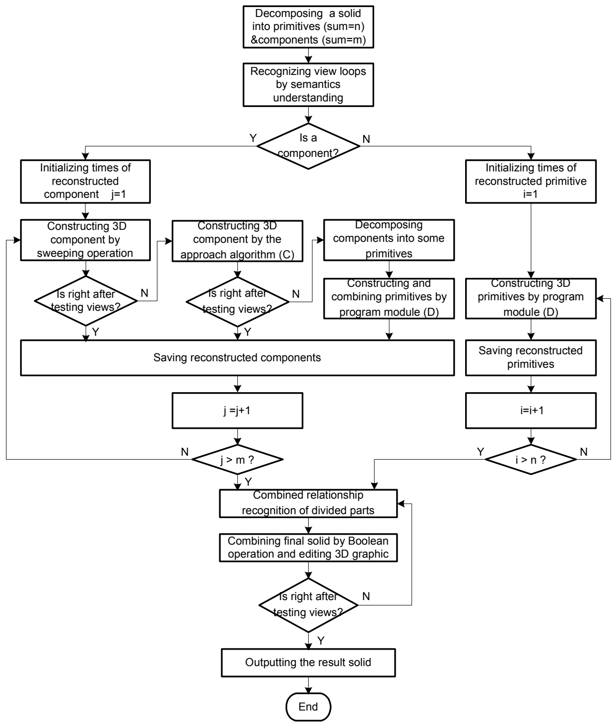

Figure 2: Whole framework of the new method

This paper simulates the method of figuration analysis and presents a new method based on engineering semantics. Reconstruction process of a goal solid is similar to that of machine assembly. Figure 2 shows the whole framework of the new method. The main steps are as follows: First, multiple views are separated and graphics feature information is extracted. Second, engineering semantics and possible a *priori* knowledge are used to recognize components or primitives and the combined relation between components and primitives. Third, sweeping representation is firstly used for components reconstruction. If unsuccessful, the approach algorithm is then arranged for 3D reconstruction. Provided that the two methods are not fit for this component, the component can be reconstructed by program module D based on primitives decomposition. Fourth, each of decomposed primitives is supposed to be among of elementary feature, sweeping feature, volume-cutting feature and boundary feature. And it is reconstructed by using a corresponding algorithm in order of precedence, i.e. CSG → Sweeping representation → the approach algorithm → B-Rep. Every reconstructed 3D component or primitive is validated by its projective views. Finally, all reconstructed components and primitives are assembled into a goal solid by Boolean operation and 3D editing operations.

2.2 Components or primitives partition and feature recognition

In order to partition components and primitives, we take full advantage of the semantics of engineering drawings to accelerate primitive recognition. According to the process of the projection, the semantics are divided into expression mode semantics, projection relation semantics and dimension constraint semantics. Furthermore, every level is classified to explicit semantics and hidden semantics. Table 1 shows categories of engineering semantics. Expression semantics understanding is the precondition of engineering drawings understanding; projection semantics understanding is the key process; understanding of dimension constraint semantics plays an assistant role. For example, the modeling information of sweeping-feature primitive, such as sectional loops and the sweeping height or path, is recognized through analyzing the explicit semantics and digging the hidden semantics. When multiple interpretations exist, views testing and visual reasoning are activated to pick out the most acceptable interpretation. Sectional views could also be involved to eliminate the unsuitable interpretations of projection views.

Table 1: Categories of engineering semantics

Levels of semantics	Categories of semantics	Principle of classifying semantics
Expression mode semantics	Explicit	Various expression modes
	Hidden	Relationship of views; simplified, abbreviatory and prescriptive views
Projection relation semantics	Explicit	Projection relation based on lines and planes
	Hidden	Primitive recognition; relationship of primitives
Dimension constraint semantics	Explicit	Dimensions of diameter, radius, angle, screw thread, *etc*. (Φ, R, °, M)
	Hidden	Dimensions of figuration, orientation, whole, *etc*.

2.3 Reconstruction of components or primitives

From Fig.3, we can see that the new method sets up a mechanism of supposing and ascertaining to reconstruct parts of the goal solid. It uses integrated reconstruction techniques. Different kinds of reconstruction algorithms are arranged to reconstruct different feature primitives according to their reconstruction efficiency from high to low. CSG is first used to reconstruct 3D primitives due to its highest reconstruction efficiency. But limited pre-defined primitives patterns restrict its applicability. So, every new reconstructed primitive is saved as a new pattern to enlarge the pattern base of CSG for feature recognition.

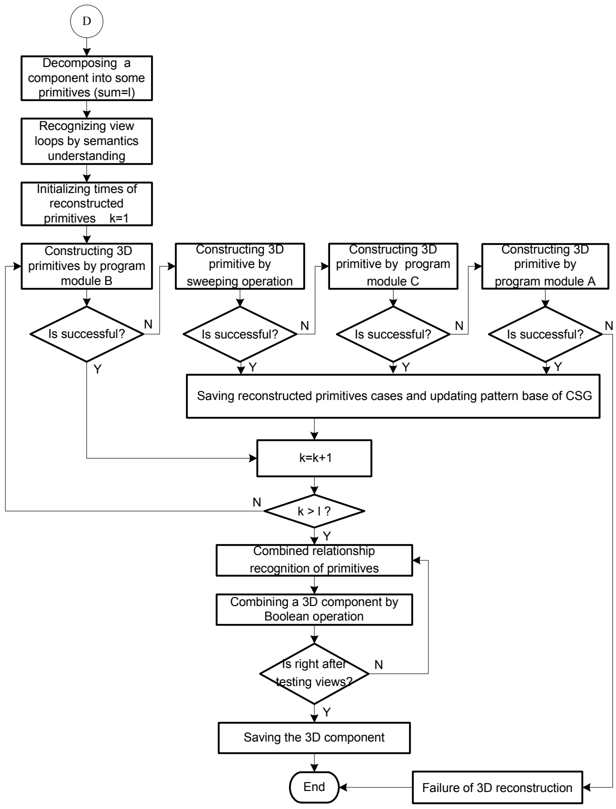

Figure 3: Framework graph of component or primitive reconstruction

3. IMPLEMENTATION

The combination of ObjectARX 2002 and VC++6.0 is used to implement the new method at the platform of AutoCAD 2004. The experimental results show that some improvements are gained by using the new method on the aspects of utility scope and reconstructed efficiency. Fig.4~Fig.7 show the process of 3D reconstruction of a mechanical part. Fig.4 shows original engineering drawings of an example and its decomposing views. From fig.4, we can see that it is divided into two components based on engineering semantics understanding. The goal solid is formed by subtracting component 2 from component 1. Fig.5 shows the reconstructed solid and its reconstructed parts. Fig.6 and Fig.7 diagram the reconstruction process of component 1 and component 2 reconstructed by different algorithms.

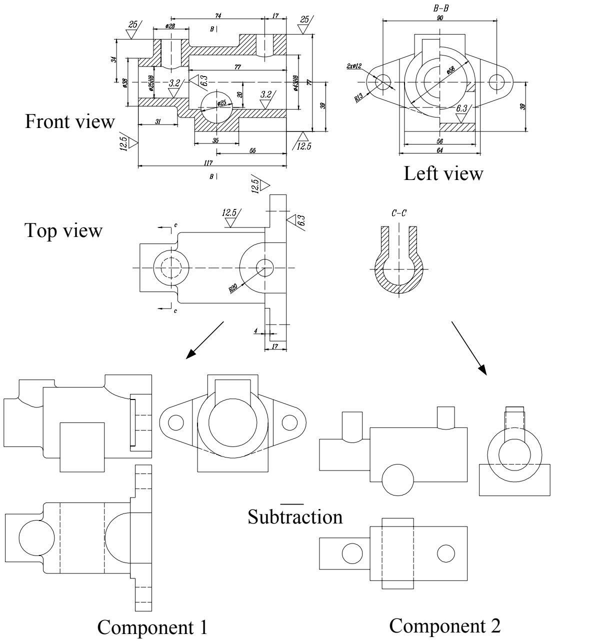

Figure 4: Original engineering drawings of an example and its processed orthographic views of decomposed parts

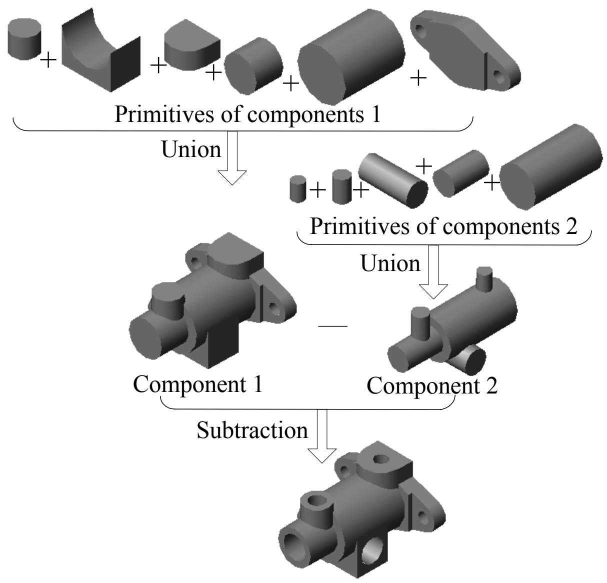

Figure 5: An example of 3D reconstructed solid and its reconstructed components and primitives

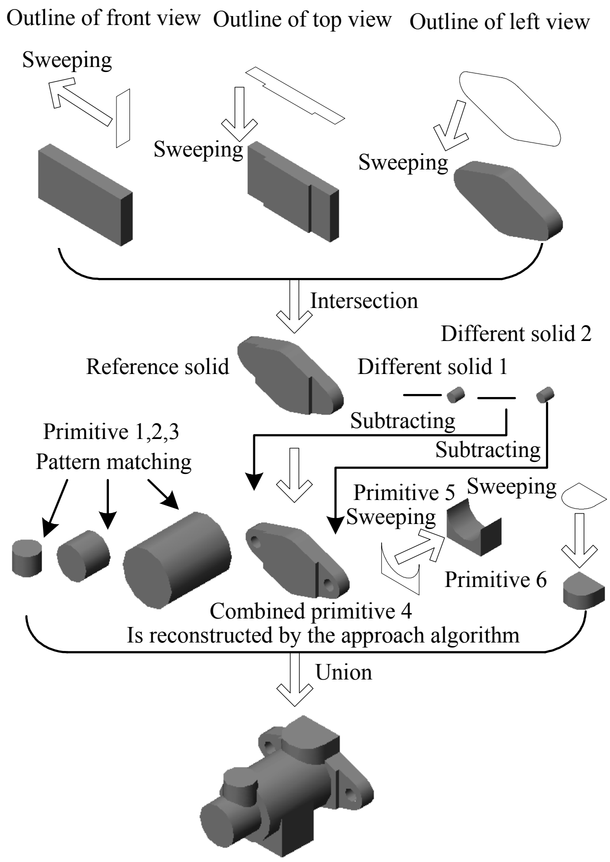

Figure 6: Reconstruction process of component 1

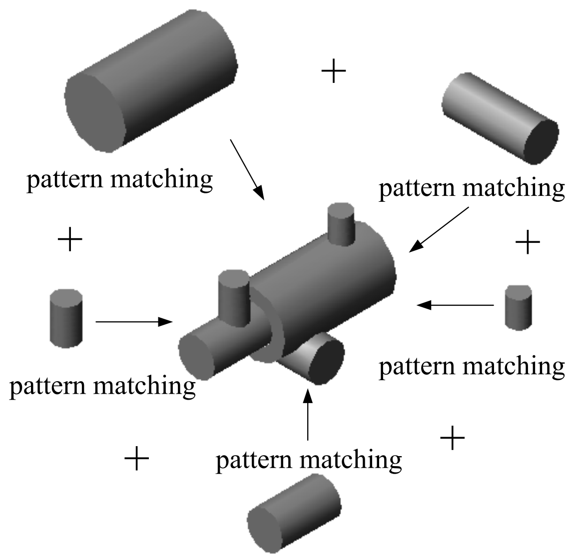

Figure 7: Reconstruction process of component 2

4. CONCLUSION

In order to enhance the practicability of 3D reconstruction, this paper presents a new method based on engineering semantics understanding. The characteristic of the new method is as follows: First, complex figuration is divided into different kinds of components and primitives and engineering semantics is used to recognizing them and their combined relationships. Second, hypothesis and views testing are adopted to reconstruct and to validate the result solid. Third, integrated reconstruction techniques are used to enlarge the figuration domain of reconstructed objects. Last, case-based reasoning is used to establish a self-learning mechanism of feature recognition.

5. ACKNOWLEDGMENTS

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