New Geometric modeling method: reconstruction of surface using Reverse Engineering techniques

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Keyword: reverse engineering, surface reconstruction, geometric modeling, Computer-Aided Design (CAD)

Abstract

In reverse engineering area, it is rapidly developing reconstruction of surfaces from scanning or digitizing data, but geometric models of existing objects unavailable many industries. This paper describes new methodology of reverse engineering area, good strategies and important algorithms in reverse engineering area. Furthermore, proposing reconstruction of surface technique is presented. A method find base geometry and blending surface between them. Each based geometry is divided by triangular patch which are compared their normal vector for face grouping. Each group is categorized analytical surface such as a part of the cylinder, the sphere, the cone, and the plane that mean each based geometry surface. And then, each based geometry surface is implemented infinitive surface. Infinitive average surface's intersections are trimmed boundary representation model reconstruction. This method has several benefits such as the time efficiency and automatic functional modeling system in reverse engineering. Especially, it can be applied 3D scanner and 3D copier.

Introduction

Reverse engineering is important issues in geometric modeling area. It is a beneficial and time reducing tool for design of composite surfaces, especially in the case of handcraft or sculptured surface [1]. The benefits of CAD/CAM is that the existence of computer models provides lots of gains in improving the quality, efficiency of design and convenient of manufacture. Reverse engineering starts with measuring an existing object. Using a laser scanner, and then that measuring data is implemented to construct a surface or solid model finally. There are several applications of reverse engineering area. One area of application is the aesthetic design in the automobile industry where designers compare real 3D object with clay or wood model. Another important area of application is to generate custom fits to human surfaces, for mating parts including the space suit, helmets and so on [2]. Reverse Engineering methodology and rapid prototyping are also applied to the medical system as artificial limbs creation and fitting, surgical implant design, prosthetic replacement design, and surgical planning from computer-aided tomography (CAT scan) data [3, 4].

The typical procedure of reverse engineering starts with scanning point data, point filtering and fairing, data reduction, curve filtering and fairing, generating surface and solid model. This traditional reverse engineering procedure is not useful for industries, because there are several disadvantages such as the complicated of procedure and tremendous amount of time for manual working. Especially, it is difficult to set a piecewise smooth and continuous model from a discrete data set automatically.

The goal of reverse engineering system can be to realize an intelligent 3D scanner. This means that based on discrete scanning point cloud, such CAD models need to be generated which not only represent the original parts approximate way, but clearly reflect the underlying structure of the object [5]. The most important thing is to apply reverse engineering technology to 3D copier and 3D scanner [6]. 3D copier or 3D scanner is the same way, that 2D photocopier takes a piece of paper and produces another piece of just like original one.

The main research area of reverse engineering focuses on two ways: edge-based method and face-based method [5]. The procedure of edge-based is data acquisition, preprocessing, segmentation, surface fitting and creation of CAD model. In data acquisition of edge-based method, the main topic of upper underlining procedure of method is the geometric part of reverse engineering. Data structures for representing shape can vary from point clouds to complete boundary representation models. However, there exist several problems such as accuracy, accessibility and occlusion. For any sensing system, the accuracy of measuring data depends on camera points and orientation. An important issue of scanning data is accessibility for which it is difficult to implement a topology of the part. Another problem is occlusion that is blocking the scanning medium due to shadowing or obstruction, so Rioux tries to eliminate occlusion in optical system by measuring a object with obstacles well [7]. But noise elimination in data sample is a very difficult task. The face-based method has rarely been applied to research works by reverse engineering area, because of more difficult finding boundary of face than edge-base method [2].

The purpose of this paper is to propose new approach to reconstruction of surface by generating patches, comparing triangular patches with normal vector, categorizing triangular patches, implementing average planar face, and trimming every edges. The underlying assumptions of proposed method are most of the parts composed of base surfaces and many parts consist of analytical base surfaces such as the plane, cylinder, sphere, and cone. If the sweep surface is included in the base surface, a vast range of product can be dealt with. The method consists of two steps. The first step is to generate a triangular mesh model from the measurement data and the second step is to generate solid models from the mesh model. In order to generate a sold model, the edges, faces, and their topology have to be found. Most of the previous research works have tried to find the edges first, and then connect them to have faces. Identifying edges directly from the triangular mesh is a very difficult because edges exist only in the mathematical world; physical objects do not have edges, and therefore, the mesh model generated from the measurement data of physical objects do not have edges. In this study, the model is constructed in the opposite way. Say, finds the faces first, and obtains their edges by intersecting the faces in order to enhance robustness and accuracy.

2. Methodology

There have been many research works on constructing triangular mesh data from point data. Fig1 shows the overall procedure of proposed methodology. After getting triangular meshes, the normal vectors of the triangular patches are compared with each other to identify whether they reside on a same plane. This process is continued until all the triangular patches are searched. Then, the planes and base geometry are expanded and intersected each other to find the edges of the object. Finally the planes are trimmed with the edges [8, 9, 10].

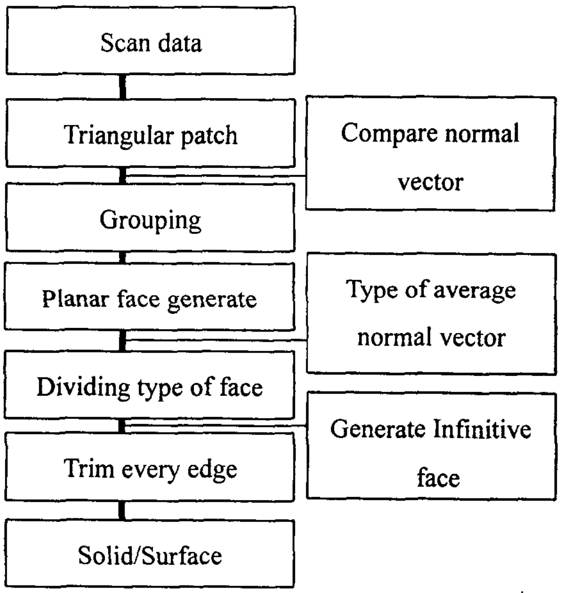

Fig 1. Overall procedure for the automatic solid data reconstruction

2. 1 Primary Algorithm

The detailed algorithm steps and the notations are as follows:

Step1: Generate triangular patch (face)

All of point datum is generated triangular patch (face). Fig. 2 (a) shows step1 graphically.

Each triangular set consists of face (f) of closed sets consisted of $f_1, f_2, \ldots, f_n$, where f_x has three points p_i, p_{i+1}, p_{i+2}.

Step2: Compare triangular patches (face) with normal vector

Each triangular patch (face) has a normal vector. Based triangular patch(Nf_1) is compared a triangular patch's a normal vector. Fig. 2 (a) shows the comparison of triangular patches with a normal vector(Nf).

where $Nf_1 \bullet Nf_2$, $Nf_1 \bullet Nf_3 \ldots$, $Nf_1 \bullet Nf_n$ ($Nf_1 \bullet Nf_2$: inner product of Nf_1 and $Nf_2, \ldots, Nf_n$).

Step3: Categorize triangular patch (face)

Each triangular patch is categorized by the deviation of normal vector. Fig. 2 (b) shows the categorization (grouping) of triangular patch. Fig. 2(c) shows the categorized triangular patch (face) graphically.

A group set (g) of closed set consists of $g_1, g_2, \ldots, g_n$

For similarly, face f_x in g_x, there exist several faces in g_n

For $(1 < i < (n+1))$

if $Nf_1 \bullet Nf_{2 \ldots n} < \varepsilon$ *(*ε*: deviation of inner production)*

then $f_1, f_{x}, \ldots_{n} \in g_y$

else $f_y, \ldots_{n} \in g_z$

end if

Here, ε depends on the accuracy of measuring equipment such as inner product's deviation of f_x's normal vector: The face set f_x consists of point p_n's coordinate value (x_1, y_1, z_1), p_{n-1}(x_2, y_2, z_2) and p_{n-2}(x_3, y_3, z_3), and p_n's coordinate value ($x_1+\varepsilon$, $y_1+\varepsilon$, $z_1+\varepsilon$), p_{n+2}(x_2, y_2, z_2) and p_{n+2}(x_3, y_3, z_3).

Step 4: Implement average planar face

In Fig. 2 (d), the planar face consists of the same patches which have the normal vectors (x, y, z). The average planar can be define of x, y and z, coordinate value, respectively. The intersection of two planar is implemented by $A_1x + B_1y + C_1z + D_1 = A_2x + B_2y + C_2z + D_2$. For example, A_1, B_1, C_1, D_1 and A_2, B_2, C_2, D_2 are the Cartesian form coefficients of the two planes such as $P_1 = A_1x + B_1y + C_1z + D_1$, and $P_2 = A_2x + B_2y + C_2z + D_2$ (11).

Step 5: Trim every edge

Fig. 2 (e) describes step5 graphically. Each planar surface is trimmed to every edge by intersection lines based on the following Boolean operation.

Let

$$h1 = -(x-2)^2 - (y-2)^2 + 4$$

$$h2 = -x + 3$$

Then express the intersections of these two half-spaces as

$$p = h1 \cap h2$$

After a surface is divided into planar face, and then the analytical face (cylinder, cone, and sphere) is identified based on the normal vector. Fig. 2(f) shows the classification of analytic faces. An analytical face is classified by several algorithms (11).

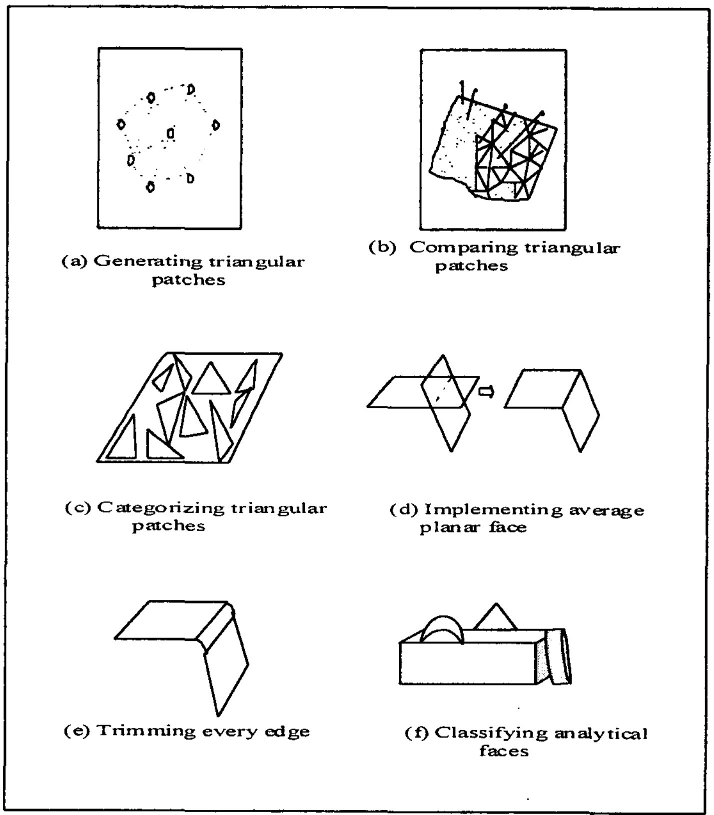

Fig.2 Procedure of each steps

One of classification types of analytical face based on the average normal vector is as follows:

i) Plane: similarity of each average normal vector. Fig3 (a) shows the shape of average normal vectors graphically.

ii) Cone: inverse cone's shape of each average normal vector that is described by fig3 (b).

iii) Cylinder: orthogonal vector of each average normal vector. Fig3 (c) shows similarity of each average normal vector's orthogonal vector.

iv) Sphere: residual i), ii), and iii). Fig3 (d) describes irregularity of each average normal vector.

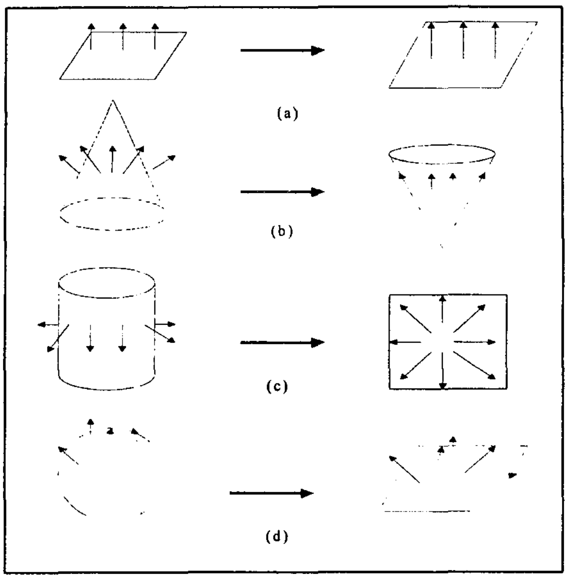

Fig.3 The type of analytical face

A composite analytical surface is trimmed to every edge by intersection lines based on the following the bellow:

- Each analytical surface (plane, cone, cylinder and sphere) is presented infinitive face.
- Each analytical surface is trimmed to every edge by intersection line and points information in the database
- Points in the database decide on trimming face following that the face includes point or is shortest path from point. Fig 4. shows trimmed face.

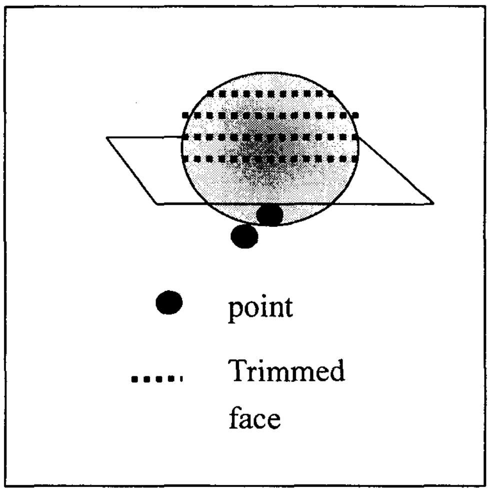

Fig. 4 Trimmed face

2.2. Data structure

The special data structure for solid model or fairly surfaces is regarded as generated points. All the point makes edges, which make faces (triangular patches). The faces (triangular patches) are divided into a patch set (group) and the faces have normal vectors and the patch sets have also average normal vectors.

A part has the child node of groups and a group has two nodes such as the parent of part and the child node of face. A face also has the parent node of groups and child of edges. A edge has the child node points.

The geometric information (point) and the topological information (edge, face, group and part) can be driven form this data structure. Especially, a point represents coordinate value saved in this data structure. Edge has regular direction such as start and end and the face (triangular patch) has CCW (Counter Clock Wise) direction edge set for keeping normal vector. A group consists of similarity face set (triangular patch set) by inner product of normal vector. A part has subpart such as plane, cylinder, cone and sphere.

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3. Implementation of the Result

The proposed algorithm has been implemented visual C++ and "open GL". In order to certificate this system, it is applied to the results and, generally, the algorithm is estimated to recognize well. Fig 5 (a) and (b) are the result. The results make distinction by printing out different color of triangle patch (the name of face in database) that is recognized to be different plain. Fig 5 (b) has a higher error ratio than (a) in measuring data. Furthermore, Fig 5 (a) and (b) are measured different ratio of machining error. As shown Fig 5 (a) and (b) is clearly presented our working a successful grouping.

Each of Fig 5 (c), (d), (e) and (f) shows the results of the experiment for the cone, the cylinder, the sphere and the composite surface composed by the cylinder and the plane face respectively. These are expressed with different colors according to averaged surface by grouping each surface, and are the information to judge the type of each surface. In Fig 5 (c) for cone, (d) for the cylinder and (e) for the sphere, the infinitive averaged surface is expressed with other colors as well. In Fig 5 (f), the result of the grouping experiment in the composite surface, shows a fine grouping.

In comparison of results on the other methods, this result shows same result of the traditional reverse engineering method, which can be gotten the result in many cases of the composite surface, in this case. However, the traditional reverse engineering has so many steps and manual operating so it has disadvantage of time efficiency, cost efficiency and accuracy. Another comparison is the edge based

method. The accuracy of the system depends mainly on resolution of camera, the chosen field of view, and the appropriate illumination. It is unfeasible and non-useful method. Furthermore, it hasn't been applied any case study.

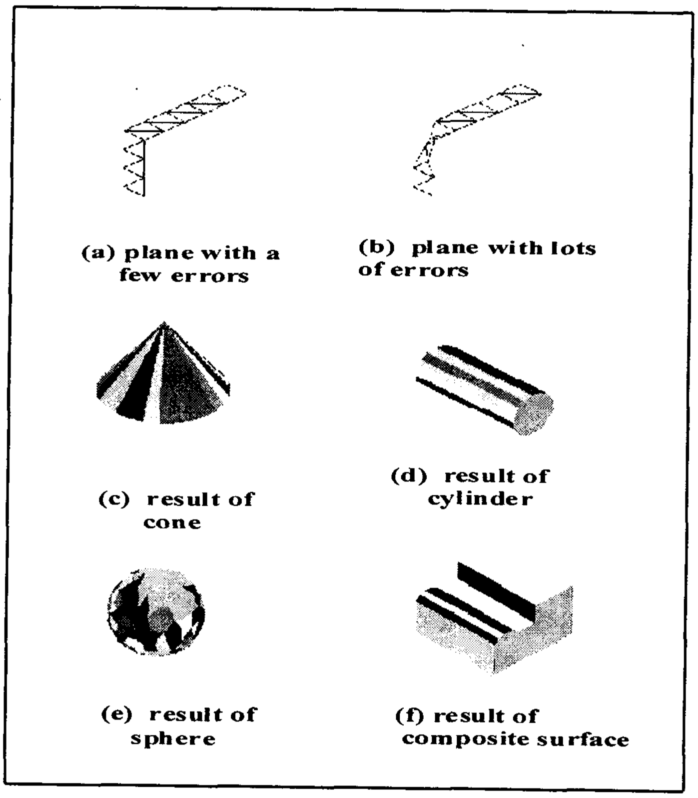

Fig 5. The result of testing

4. Conclusions

In this paper we proposed a new methodology for the reconstruction of surface based on the measuring data using laser scanner. The point data is linked to edge information, which constructs the face. By the proposed algorithm, these faces are grouped and have group information. Also, according to its types of information, e.g. the plane, the cylinder, the cone and the sphere, each group consists of sub-part and then is added to construct a part. Finally, it is possible to extract information that is related to the reconstruction of composite surface. Since each step can be processed automatically without human intervention, it is possible to be directly applied to 3D fax. Furthermore, the proposed algorithm is superior to computational efficiency and automatic functional modeling system. For the further studies, it is necessary to reconstruct the composite surface with free-from.

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