Data Reduction Methods for Reverse Engineering

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Reverse engineering is an emerging technology that promises to play a role in reducing product development time. Reverse engineering in this paper refers to the process of creating engineering design data from existing parts. It creates or clones an existing part by acquiring its surface data using a scanning or measurement device. Recently, laser scanning technology has improved significantly and has become a viable option in capturing geometries of complicated design models. 3D laser scanners have become more accurate and the speed of data acquisition has increased dramatically. However, they generate up to thousands of points per second, and handling the huge amount of point data is a major problem. It becomes quite important, therefore, to reduce the amount of acquired point data and convert it into formats required by the manufacturing processes while maintaining the accuracy. This paper presents methods that can reduce efficiently the amount of point data.

Keywords: Point cloud data; Point data reduction; Reverse engineering; 3D laser scanner; Uniform and non-uniform grid methods

1. Introduction

Products are manufactured from 2D or 3D CAD models, but these CAD models are not always available in the production environment, and thus it is often necessary to generate a model from an existing physical part. Reverse engineering technology makes it possible to recreate an existing part by reconstructing its surface geometry in a 3D digital file using a scanning or measurement device. This technology enables us to create a CAD model of a part that has no design data or has gone through many design changes. For certain industries such as in the automotive industry, the part geometry is obtained from a mock-up model using this technology.

In capturing surface information, either contact or non-contact measuring devices can be used. Coordinate measuring machines have usually been used in the past for capturing surface information. These machines typically use touch probes and the data acquisition process is very slow when they are used for measuring parts having complex freeform surfaces. In contrast, non-contact devices such as 3D-laser scanners are extremely fast in data acquisition, but they are rarely used in production lines because of their poor accuracy compared to that of contact devices [1]. Among these devices, those using laser-scanning technology have been improved significantly in recent years, and are now being used in the production mode [2]. However, there are problems in using these scanning devices since they produce extremely dense point data at a great rate. Not all these point data are necessary for generating a surface model, moreover, bottlenecks are created owing to inefficiencies in storing and manipulating them. Therefore, it takes a long time to generate a surface model from these scanned data.

To avoid these problems, it is important to reduce the amount of scanned data while maintaining the required accuracy. This paper presents data reduction methods that can reduce the amount of point data acquired during laser scanning. The proposed methods are applied to different types of surfaces and the results are discussed.

1.1 Previous Research

Contact devices were usually used to acquire surface geometry in the past, and research issues were mainly on point-sampling strategies for different types of surface. The amount of point data did not need to be reduced for contact devices. However, in recent years, some workers have shown interest in managing the large amount of point data acquired by laser scanners. Some research related to point data reduction for reverse engineering is described below.

Martin et al. [3] proposed a data reduction method using a uniform grid in their EU Copernicus project. Their method uses a “median filtering” approach, which has been widely used in image processing. The procedure starts by building a grid structure, and the input data points are assigned to the corresponding grid. From all of the points assigned to a given
grid, a median point is selected to represent data points belonging to that cell. This approach overcomes the limitation of averaging or simple sampling methods. Their method, however, has a drawback due to the use of uniform size grids that can be insensitive in capturing a part shape.

Fujimoto and Kariya [4] also indicated that the amount of data should be reduced since a large amount of point data causes problems in downstream manufacturing operations. They suggested an improved sequential data reduction method for 2D digitised point data. Their method guarantees that an error range of the reduced data remains within the given angle and distance tolerances.

Chen et al. [5] suggested a method to reduce the point data by reducing the number of triangles required in a polyhedral model. They generated the STL file of a part directly from the point data acquired by a coordinate measuring machine, and reduced the amount of data by decreasing the number of triangles in the STL file. Triangles in planar or near planar regions are combined by comparing the normal vectors of neighbouring triangles. As a result, larger triangles are formed for flat areas and smaller ones for highly curved areas. They demonstrated their algorithm by reducing the number of triangles in an STL file of a human face digitised by a CMM machine.

Hamann [6] also presented a method of data reduction for triangulation files based on an iterative triangle removal principle. As a measure of the reduction of file size, each triangulation is weighted according to the principal curvature estimates at its vertices and interior angles.

Ve ´ ron and Le ´ on [7] introduced an approach to reduce the number of nodes of a polyhedral model using error zones assigned to each point of the initial polyhedron so that the simplified polyhedron intersects with each error zone.

Hamann and Chen [8] proposed a method to reduce the point data in making various planar curves, compressing 2D images, and visualising volumes. In their method, points are selected with respect to local absolute curvature estimates for piecewise linear curve approximation. The degree of reduction is controlled either by the number of points to be selected or by the error tolerance level.

Major research efforts in the existing data reduction methods lie in manipulating polyhedral models. Various schemes are also used to reduce the amount of point data from the initial point clouds; however, none of the existing methods has considered the characteristics of the scanning device.

2. Reverse Engineering by Laser Scanning

The reverse engineering process consists of the following steps, as shown in Fig. 1: point data acquisition, noise filtering, data reduction/arrangement/registration, segmentation, curve/surface fitting, and 3D surface model generation.

The data acquisition step creates raw point data to work with and it is considered as a crucial step in reverse engineering since in many cases, the quality of raw point data determines the quality of the resulting surfaces. Once raw point data are acquired, noisy data points, so called outliers or spikes, generated during a scanning process, must be eliminated. The quality of point data can be further improved by performing pre-process operations such as spike removal, smoothing and merging. For spike removal, several methods can be used:

1. The angles between two consecutive points are considered, and a point that makes an angle with the previous point larger than the given value is eliminated.
2. The points can be moved to a median value.
3. The points can be moved either upward or downward close to the given level along the specified axis within the allowable distance [9].

The data reduction methods are applied after the removal of spikes and they should be performed with consideration of the characteristics of the scanning devices.

2.1 3D Laser Scanning

A 3D laser-scanning device acquires the surface information of a part, by sending laser beams which are radiated from the surface and received by CCD cameras. In general, the probe of a laser scanner consists of a beam projector radiating the laser beam and a CCD camera sensing the reflected beam from the surface. The laser beam can typically be categorised as a point type, or a stripe type. A stripe-type scanner radiates a line of laser beams, called a stripe, onto the surface so that several points can be acquired at once, whereas a point type laser scanner obtains only one point at a time. Laser scanning devices can also be classified based on the configuration of the machine, as shown in Fig. 2.

There are other configurations, but these three are the most popular ones. Each one has advantages and disadvantages; the choice of a machine depends on the characteristics of the part to be scanned, as well as its application. The first type shown in Fig. 2(a) uses three linear axes that are perpendicular to each other. This one follows the same structure as for the traditional fabrication machines and shows better accuracy compared to the others owing to its structural stability. A coordinate measuring machine can be retrofitted to form this type by mounting a scanning probe. Extra degrees of freedom can be obtained by adding a rotary table with tilt and other motions. In the second type of device, the scanning is perfor-