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Aeroengine turbine blade modeling based on scattered point model reverse engineering

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Abstract. Aiming at the problems such as large obtained point cloud data density, various redundancy point and heavy processing tasks of 3D optical inspection technology of large-scale complex surface products in the reverse engineering, the preprocessing technology and workflow of mass point cloud obtained by optical detection are studied, and the final criterion of $\Delta(S, S')$ in point cloud sampling is proposed in this paper, which aims at achieving the given maximum allowable error or number of specified points in the principle of satisfying the high accuracy, fast speed, and proper simplification degree, and is suitable where there is high requirements for reconstruction geometric accuracy. Taking the blade of an aircraft as an example, the accuracy and feasibility of the 3D optical detection point cloud sampling technique are proved by sampling and reverse modeling accuracy analysis.

Key words. Point cloud sampling, Aircraft blade, 3D detection, Reverse engineering, Optical detection.

1. Introduction

With the development of modern industrial manufacture, more and more complex surface products appear in military and civilian industries, these parts adopt much irregular complex surface, and the design, production, detection, testing and other aspects need for a large number of real digital operation and 3D measurement, there is an urgent need for rapid, efficient, accurate, and mobile 3D measurement method and reverse design technology. Especially, the curved surface detection of large-scale complex curved surface products is always the key technical problems in the production, such work piece is generally measured using profiling method under the workshop conditions, which has the problems of less measurable cross section and low measurement accuracy, the three-coordinate measuring machine and other

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contact measurement feature high accuracy, but there are disadvantages including slow data acquisition speed, high measurement cost, on-line detection difficulty, non-continuous measurement data, and only key point detection availability. In view of the limitations of the traditional contact measurement method, the non-contact optical methods used to measure the object surface profile shape [1], such as laser triangulation method, Moire projection method and other industrial vision measuring methods has the characteristics of high sensitivity, fast measurement speed, and much data acquired and so on, however, because of the restrictions on the working principle, both the measurement accuracy and measurement resolution are low [2].

In order to overcome the limitations of the above measurement methods and realize the fast and accurate measurement of large-scale complex surface products, 3D optical surface structured light scanning technology (surface scanning technology) is widely applied. This technology quickly obtains the geometric characteristics of the surface in the form of multi-range point clouds, and applies the point cloud processing technology in the reverse design method to get the digitized model of the object. It is significantly characterized by its matching with industrial close-range photogrammetry technology (photogrammetry technology). Photogrammetry is used to obtain the global mark point of the measured object, providing the basis for the registration of the point cloud obtained by the subsequent scanning; the surface scanning technology is based on the global mark points of work piece obtained by photogrammetry technology. The point cloud automatic [3] registration of scanning work piece is realized, the geometric information of object surface is quickly reproduced, and the CAD digital model of object is constructed.

In reverse engineering, data acquisition is the basis of point cloud processing. It is an important research content in reverse engineering to collect the geometric characteristic data with high efficiency and high accuracy [4,5]. The surface scanning technology is different from the traditional measurement method as it is optical non-contact measurement not affected by the surface complexity of the work piece, which can get a lot of data information in a short time, and quickly provide raw data for reverse design and 3D quality detection. Its advantages make 3D optical measurement technology widely used in many fields. However, the density of data acquired by these devices is very large. When measuring, they are greatly influenced by the scope of work and the complexity of the measured parts. When the data in multiple views is converted to the same coordinate system, there are lots of redundant points. Massive data points are redundant for surface reconstruction and quality detection. It also brings great inconvenience to data storage and subsequent processing [6,7]. Therefore, sampling the scanned data under the condition of satisfying the accuracy is an important work of reverse processing and 3D detection [8].

2. Point cloud preprocessing technology

2.1. Point cloud preprocessing process

In combination with Fig. 1, the process of point cloud preprocessing includes the acquisition of massive point cloud data, point cloud preprocessing and surface reconstruction. Preprocessing technology is the core and difficulty of the research, which mainly includes:

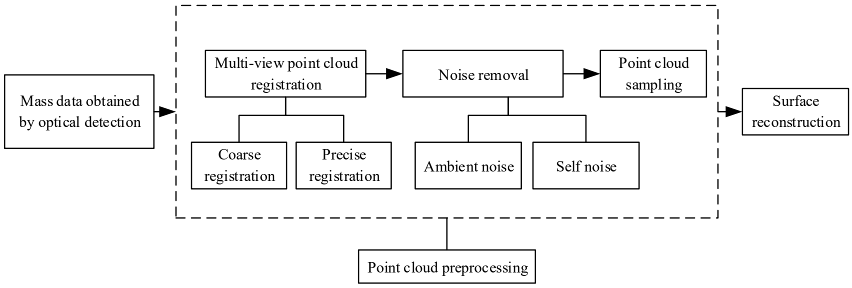


Fig. 1. Point cloud preprocessing process

(1) Multi-view point cloud registration

When the 3D optical surface scanning device collects data, it is necessary to measure the object from multiple angles due to the limitation of the scanning range and azimuth. Different angles correspond to different local coordinates. The final result needs to be unified into the world coordinate system. Multi-view point cloud registration is divided into coarse registration and precise registration. Coarse registration makes use of the spatial geometric relationship between mark points, and performs rough positioning in the principle of keeping constant in different views.

The ICP algorithm is used for precise registration, and the data obtained from different views are overlapped. According to these overlapped parts, the mapping of corresponding points is established. Based on the least squares algorithm, the transformation matrix is solved, and the given accuracy is achieved by iterative calculation to achieve the conversion of data from different views to the same coordinate system.

(2) Noise removal

For optical non-contact measuring equipment, there are two main sources of noise.

Firstly, it is influenced by the singleness of the geometry, structure, color of the surface, the arrangement of the stripes, the roughness, and the ambient light of the measured work piece.

Secondly, it is caused by the error of the measurement system itself, such as CCD camera resolution, distortion error, computer processing error, manufacturing accuracy of mechanical equipment, calibration error, and ruler accuracy and so on.

The reconstruction of the noise point interference model affects the geometric accuracy of the final CAD digital model. It needs to be subject to fairing and noise reduction. The points connected by the dotted line in Fig. 2 represent the points measured by the laser scanning, and the points connected by the straight line represent the points after the fairing. The Gauss filtering method (Fig. 2 (b)) is used for scattered point clouds. Gauss filtering makes use of the linear smoothing filter based on Gauss function, which can effectively remove the noise that obeys normal distribution, and keep raw data characteristics well while filtering.

Besides, median filtering and average value filtering are also used for point cloud filtering. The average value filtering method (Fig. 2 (c)) takes the statistical mean of the data points in the filter window as the value of the sampled points to replace the raw points, and changes the location of the point cloud to make the point cloud smooth. Median filtering (Fig. 2 (d)) takes the average value of 3 adjacent points to replace the raw point to achieve filtering. This method has a good effect on eliminating data burrs.

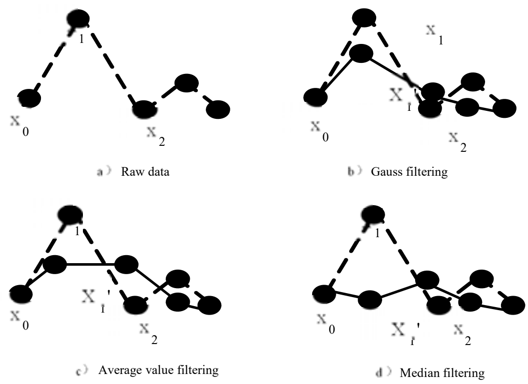


Fig. 2. Commonly used filtering methods

(3) Point cloud sampling

Because of the different scanning equipment, the point cloud is mainly divided into the scattered point cloud obtained by the white light scanning and the scanning line point cloud obtained by the laser scanning. The structured measured data stored according to the scanning line generally uses the special simplified algorithm for the effective use of known information. This paper mainly deals with point-based scattered point cloud sampling.

As there is no given geometric information of the surface required to be reconstructed in scattered point clouds, the geometric relationship of the point clouds is generally established. According to the differences in topological relationships, the classification of point cloud simplification is as shown in Fig. 3.

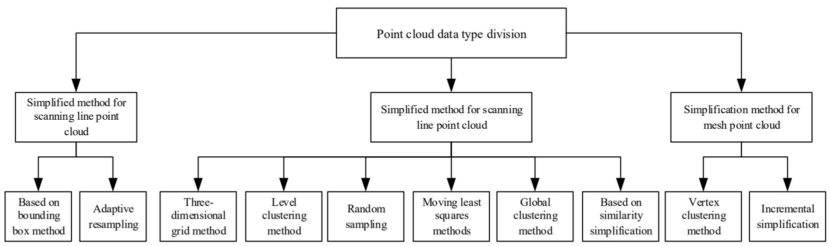


Fig. 3. Classification of point cloud sampling algorithm

3. Point cloud sampling

3.1. Design principles of point cloud sampling

Point cloud sampling technology is an important step in point cloud preprocessing in reverse engineering, which must meet the four principles:

(1) Can handle big data. The big data obtained by scanning generally contains tens of millions of points or hundreds of pairs of point clouds, which require the system to be capable of processing.

(2) It shall be fast. Nowadays, the competition of the market is increasingly fierce, the development cycle of the new product shall be short, and the time for the user to deal with the reverse modeling shall be as short as possible.

(3) The accuracy of the model shall be high. In order to meet the requirements of the given accuracy, the accuracy of the digital model obtained by the fitting of the point cloud shall be as high as possible after sampling.

(4) The robustness of the system shall be good. The prerequisite for good robustness is dealing with point clouds in a variety of troublesome conditions, and processing big data without program crash or dead halt.

3.2. Ultimate goals of point cloud sampling

The ultimate goal of measuring the well-formedness of point cloud sampling algorithm is not to keep more original points, faster processing speed, and less data points, but to use the least points to represent the geometric characteristic information and pursue the fastest processing speed and the shortest calculation time based on it.

$P$is assumed to be the original point cloud, the corresponding surface is S, and the point cloud P' after sampling is made up of a n points, and the fitting surface is defined as S', then,

$$\Delta\left(S, S'\right) = S' - S\,. \tag{1}$$

Where:

$\Delta\left(S, S'\right)$— normal deviation of the two surfaces;

S'— fitted surface;

S— CAD digital model of the existing product.

$\Delta\left(S, S'\right)$ shall meet the formula (2),

$$\Delta\left(S, S'\right) \leq E\,. \tag{2}$$

Where:

E— normal deviation of the point cloud set according to the user's requirements.

The ultimate goal of sampling is to make n as small as possible under the precondition of satisfying (2), and the point cloud obtained after sampling is not completely a subset of the original point cloud.

The measurement index of the performance of point cloud sampling algorithm:

(1) High accuracy. The deviation between fitting surface and ideal surface of point

cloud after sampling must ensure that the characteristic information of original point cloud can be retained as much as possible within the allowable range of accuracy.

(2) Fast speed. The speed of sampling algorithm shall be as fast as possible; the innovation of modern design products is speeding up. If it takes too much time in reverse engineering, it will bring inconvenience to scientific research, enterprises and institutions. Even for an excellent algorithm, if the computing time is too long, the outlook of market application is foggy.

(3) Proper simplification degree. The data size from the point cloud after sampling. The purpose of sampling is to reduce the number of point cloud data, and to reduce the number of data as much as possible under the premise of ensuring the accuracy. But too few points will make subsequent modeling difficult; therefore, appropriate simplification degree shall be selected based on the actual need.

In practical applications, the algorithm is difficult to meet the above three indicators, and it is necessary for the user to consider it in a comprehensive way. It is necessary to select the appropriate algorithm according to the different purpose of the application. The criterion of sampling termination is to achieve the given maximum allowable error or the number of specified points, which is especially suitable for occasions with high requirements for reconstruction geometry accuracy.

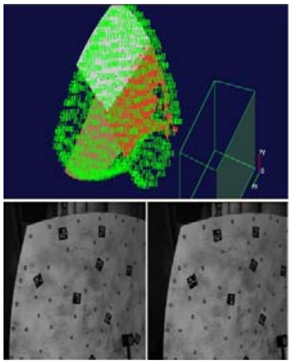
4. Application example

The aircraft blades of a domestic steam turbine factory are taken as the research object, which are detected with the combination of photogrammetry technology and surface scanning, and the parallel preprocessing of the point cloud data obtained by scanning is achieved. The processed data are compared with the CAD model of the work piece. The original point cloud collected by the blade model has more than 2 million points. The point cloud obtained by 1/80 sampling by hierarchical clustering method has 25 thousand points, which is able to meet the requirement of the number of measurement points compared with the hundreds of points acquired in the work piece measuring by the traditional three-coordinate measuring machine.

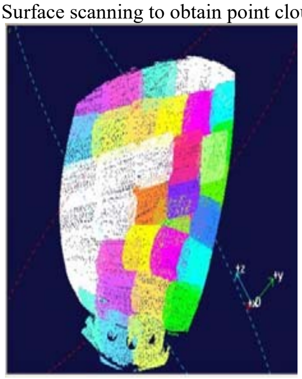
3D detection and point cloud processing process are as shown in Fig. 4, Fig. 4 (a) shows the photogrammetry of blade; Fig. 4 (b) shows the point cloud obtaining by surface scanning technology; Fig. 4 (a) shows the final single-range point cloud after point cloud preprocessing and sampling; Fig. 4 (b) shows the coincidence of the point cloud and the actual CAD digital model after sampling in Geomagic Qualify, chromatography icon point cloud processing technology can meet the requirements of engineering practice.

5. Conclusion

This paper has three main points: firstly, the necessity of data preprocessing in reverse engineering is analyzed, after the point cloud preprocessing, the scattered and rough point cloud obtained in data measurement becomes smooth and fair with only a small amount of miscellaneous points, point cloud obtained greatly



(a) Surface scanning to obtain point clouds



(b) Global matching of point clouds

Fig. 4. Point cloud processing in 3D detection process of turbine blade

reduces the operation difficulty in 3D model reconstruction, and lays a good data foundation for model reconstruction. Secondly, the final criterion $\Delta(S, S')$ of point cloud sampling is put forward, which aims at achieving the given maximum allowable error or number of specified points in the principle of satisfying the high accuracy, fast speed, and proper simplification degree, and is suitable where there is high requirements for reconstruction geometric accuracy. Finally, taking an aircraft blade as an example, the accuracy of sampling and reverse modeling is analyzed, and the correctness and feasibility of 3D optical detection point cloud sampling method is proved.

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