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Point Cloud Process of Laser Scanning with a Mathematical Noise Model

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Abstract. Considering the unreasonable noise of laser scanning point data during measuring, which causes the reconstructed curve and surface rough, some problems are analyzed to deal with noise. The mathematical noise model on scanning point cloud is proposed, which consists of deterministic and random noise error, and the random error mainly consists of geometric error and measurement one. The data process is proposed to reduce noise and to simplify data. The noise process consists of obvious noise removed, random filter algorithm and data fairing with an optimized correction value. Due to redundant data about mass point cloud, method of combining deviation parameters with allowed angle is proposed to simplify point cloud. The experiments show that the proposed method has many obvious advantages than a single algorithm of data processing, such as all sorts of noise data can be removed respectively, mass data can be streamlined. And the proposed algorithm has the advantages of high reservation of curve and surface reconstruction of point cloud.

Introduction

With the development of industrial technology, the equipment not only has excellent quality and reasonable cost, but also has smooth shape and personalized appearance, to meet the needs of modern industrial development. Since these products appearance are generally composed by complex freeform, it is difficult to describe with rigorous mathematical formulas of traditional mode. Now reverse engineering technology becomes one of dominant design methods for complex curves and surfaces of product development [1,2]. Data acquisition is the first step in product reverse remodeling, which laser method is widely used to obtain data. From the point of measurement, this non-contact method can really achieve 'zero contact force measurement', which effectively avoid the system and random error of force in the course of high precision measured, and at the same time this method has advantages of convenience, fast speed and high efficiency.

However, due to the optical change of measured environment, and the impact of measured device itself, such as laser speckle, nonlinear error of CCD, resolusion and sampling error, electrical system noise, and thermal noise, noise data is inevitably existed in measured point cloud data, which can be also caused by surface roughness of the measured object, crinkle and other surface defects. Then the difference between reconstructed CAD model and referred entity is directly appeared, which is seriously affected product accuracy and the corresponding performance requirements [3-5]. Therefore, noise data of obtained data can be processed as first step before model reconstruction .

Laser scanning can produce mass high-density point cloud data. Although theoretically a large amount of data reconstruction model has a higher precision, not all points are useful on the subsequent surface reconstruction. These redundant point cloud data cause to storage difficulties, to reduce operating efficiency, to run worse of algorithm robust[6]. Thus, under the promise of maintaining the original shape accuracy, it is necessary to compress the denoised point cloud data.

Feature Description

Mathemaical Model of Data Contained Noise. Point cloud data inevitably contains noise, which obtained by laser scanning from entity. There are two mainly categories to summarize these factors produced noise. One is the error produced by surface factors of measured objects, such as surface roughness, waviness, and other defects. Other is the error caused by measurement system itself, such as the measuring apparatus accuracy, the CCD camera's resolution, vibration, etc. During laser measurement, first the pixel of two-dimensional image captured by CCD camera is usually processed, second space coordinate values about a series of object measured are obtained from the third dimension information extracted, third it is expressed as a set of points $\{A_i = f(x_i, y_i, z_i) \mid x_i, y_i, z_i \in E^3\}$.

$f(x_i, y_i, z_i)$ is composed of two parts: values of object measured $g(x_i, y_i, z_i)$, and measurement error $e(x_i, y_i, z_i)$ respectively. In them, $g(x_i, y_i, z_i)$ includes two components, i.e. deterministic component $g^Q(x_i, y_i, z_i)$ and random one $g^S(x_i, y_i, z_i)$. And error $e(x_i, y_i, z_i)$ is divided into system measurement error $\alpha(x_i, y_i, z_i)$, and system random error $\beta(x_i, y_i, z_i)$. Then measured point is represented as mathematical expression in equation (1).

$$f(x_i, y_i, z_i) = g^Q(x_i, y_i, z_i) + e(x_i, y_i, z_i) = g^Q(x_i, y_i, z_i) + g^S(x_i, y_i, z_i) + \alpha(x_i, y_i, z_i) + \beta(x_i, y_i, z_i) . \quad (1)$$

In the formula (1), $g^Q(x_i, y_i, z_i)$ is the ideal value of measured surface. $g^S(x_i, y_i, z_i)$ is the geometric deviation between measured surface and ideal value, arised from surface roughness, waviness, and other surface defects. $\alpha(x_i, y_i, z_i)$ is the deterministic error generated by measurement system itself, and this uncertainty error possess a certain regularity. $\beta(x_i, y_i, z_i)$ is the random measurement error caused by such factors as laser knife speckle, electrical noise of measurement system, and thermal noise.

In order to retain geometric shape of object in the subsequent reconstruction of curves and surfaces in reverse engineering, it is as much as possible to make $f(x_i, y_i, z_i) \to g^Q(x_i, y_i, z_i)$, in which adverse impact of error factors can be eliminated at its utmost. In figure 1, $g^S(x_i, y_i, z_i)$ and $\beta(x_i, y_i, z_i)$ are regarded as random error. To eliminate uncertainty error, method of big noise removal is used in this paper. The processing method of noise points generated by random error $g^S(x_i, y_i, z_i)$ and $\beta(x_i, y_i, z_i)$ has the following characteristics. First, in measurement data, many strong interference signals can be appeared, which they have large amplitude, to cause a large spike in the sectional line, and high frequency, to last only a very small period of point cloud data. They have a wide band and higher frequency, as reflected to the burr in measured data, method of large noise removed is used to eliminate partial noise of such random noise. Second, in addition to the above strong interference signal, there is also some low-frequency random signal changed closely to the measured surface in original data, which it has small signal amplitude, and has glitches of reconstructed curves and surfaces. It is difficult to completely filter out for this low-frequency random signal.

Massive Point Cloud Streamlined. As point cloud acquired by laser scan contains mass data, there are such questions to deal with as computational complexity, long time, and a lot of memory space taken up, although reconstruction model accuracy of mass points will be higher in theory. Therefore, under the promise of ensuring reconstruction model accuracy, mass points must be streamlined.

In summary, the whole process dealt with original point cloud data includes four coherent algorithms, i.e. obvious noise point removal, random filtering, optimized amount fairing, and point cloud streamlined. The first three are used to remove noise generated by uncertainty error $\alpha(x_i, y_i, z_i)$, measurement random error $g^S(x_i, y_i, z_i)$, and system random one $\beta(x_i, y_i, z_i)$ respectively. The fourth is used to remove redundant point.

Process Algorithm Description

Significant Noise Point Removed. Document [7] uses noise calibrated to eliminate spoiled pixels, and it needs people involved, and also has the disadvantages of low efficiency and poor accuracy. In order to avoid these shortcomings, an algorithm to estimate point curvature is applied to remove large noise [8]. A specific description of this method is given below. Select whole points of a section line, and store them to array A. Take three points $P_{i,j}$, $P_{i,j+1}$ and $P_{i,j+2}$ in order from the same cross-sectional line, curvature of point $P_{i,j+1}$ can be obtained. Calculate whole points in order of a sectional line, curvature values of all can be calculated (except for two endpoints). Based on curvature value, calculate its curvature difference between two equal distance points. Find out n points which the curvature difference is larger than predetermined threshold value. Then the points are divided into n+1 segments by these points. Finally, fit them into curve respectively.

Random Filter Denoising. The random filter algorithm in literature [9] is used to delete such random noise as $g^S(x_i,y_i,z_i)$ and $\beta(x_i,y_i,z_i)$, generated by low-frequency signal and high-frequency one, and the threshold is adjusted in this paper. The detailed description of this algorithm is given below. Let point data as a point set $\{P_i, i=0,1,\cdots\cdots,n\}$, and i represents the number of points. Suppose the distance between point i and point $i+1$, point $i+2$ is d_1 and d_2 separately, between point i and $i+2$ is d_3. Its algebraic expression is given in equation (2).

$$d_1 = |P_{i+1} - P_i|, d_2 = |P_{i+2} - P_{i+1}|, d_3 = |P_{i+2} - P_i|. \tag{2}$$

Given variables $\Delta = d_3 - d_1$ and $\delta = |d_2 - d_1|$, and given threshold ε_1 and ε_2. θ_1, θ_2 and θ_3 are angles between two sides separately, which is algebraic. And its value is positive as counter-clockwise, vice versa. See figure 1.

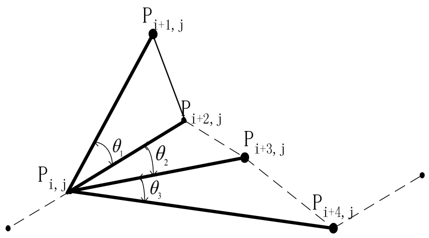


Fig.1 Map of point distribution

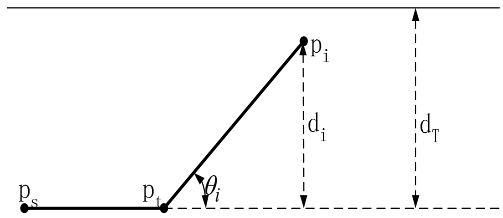
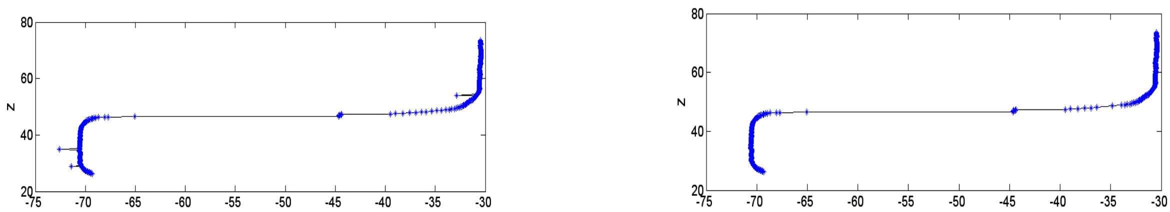


Fig. 2 Principle of compression algorithm

Fairing with an Optimized Correction Value. In order to acquire point cloud data which can eliminate the residual random noise $g^S(x_i,y_i,z_i)$ and $\beta(x_i,y_i,z_i)$ after significant noise point removal and random filter removed noise, and can truly reflect the original design view, a fairing method with optimized correction value [10] is used. The fair method includes two blocks, rough fairing and fine fairing. Bad data is identified according to curvature sign and its one-order difference respectively. The direction of each modified point is along the positive or negative way of G which points to the triangle's center, and it is located according to energy function. The given distance is first set an initial value, then it searches the optimized correction value according to a certain step of equation. This search is terminated until energy function equation satisfies the minimum value within a certain value.

Deviation Parameters Streamline. As laser scan point has the disadvantages of data intensive and mass, not easy to storage, it is necessary to compress data during process under the promise of ensuring accuracy after compression. Li Jian[11] proposed compression algorithm with deviation parameter d_i, in which mass point cloud data is processed sequentially after big noise removed, random filtering, and fairing with optimized correction amount. However, this method doesn't take full account of maximum allowable value θ_T of angle among three adjacent points. And it easily leads to compress too quickly and to cause geometric distortion of reconstructed object when these three points approximate a straight line or gyration radius of quadratic curve is large. Thus, an improved compression method is ued which is simple and intuitive. And it compresses points according to tolerance value d_T combined with maximum allowable angle θ_T. The principle is shown in figure 2. Detailed steps refers to [12].



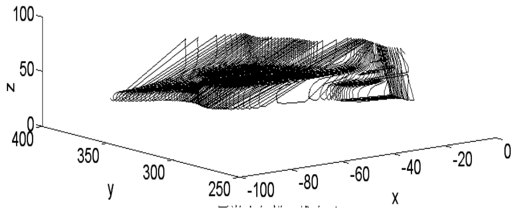
(a) original curve (b) noise removed curve

Fig.3 Simulation output with sectional method

Algorithm Output

The process of laser scanned point cloud includes four consecutive algorithms: obvious noise point removal, random filtering, data smoothing, and point cloud streamlined. The example used comes from a brake parts. A three-dimensional or two-dimensional point cloud is the input and output data after each algorithm run. The typical output of each method achievement is given below.

The output of significant noise removal algorithm is shown in Figure 3. The specific location of illustrated section line is $y = 337.8030$.


(a) original 3D point cloud

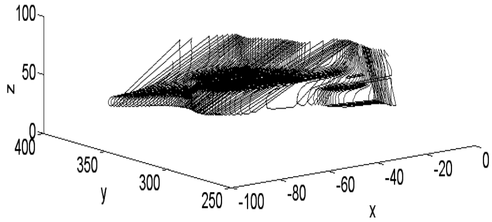
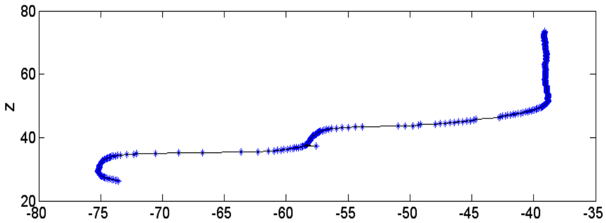

(b) the random filtering output I

Fig.4 Simulation output with a random filter algorithm I


(a) original curve

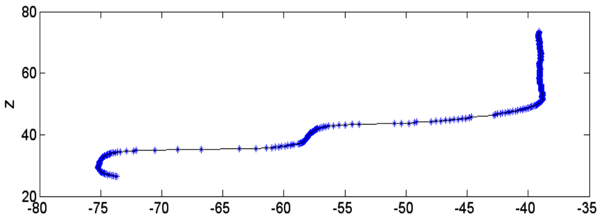
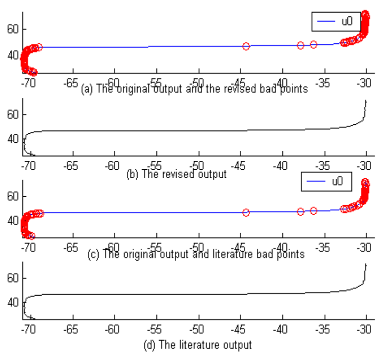

(b) the random filtering output II

Fig.5 Simulation output with a random filter algorithm II

The program output of random filtering algorithm is shown in Figure 4 and Figure 5. Figure 4 is output of three-dimensional, and Figure 5 is specific location $y = 360.8060$ of section line.



u0—original curve

Fig. 6 Outputs of improved and document

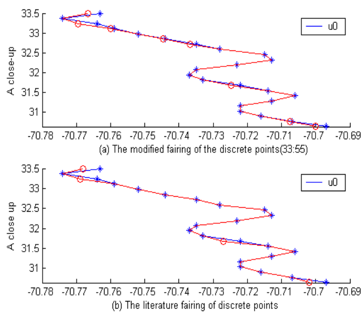


Fig.7 Closed-up curves (local view)

The procedure outputs of curve smoothing see Figure 6, and the specific location of section line is y=334.8060. As in Figure 6, data point is so dense that it is not easy to compare smoothed effect between corrected algorithm and literature one [13], output of a small amount of data is given, as shown in Figure 7.

The output of compression method with deviation parameter is shown in Figure 8. Its specific location of sectional line is $y = 372.8020$, and the maximum allowable angle is $\theta^T = 5°$. In Figure 8, first figure shows original output before compression, and second one shows compressed output in which tolerance value is dt=0. 02, and its compression value is 150/362 = 41.44%.

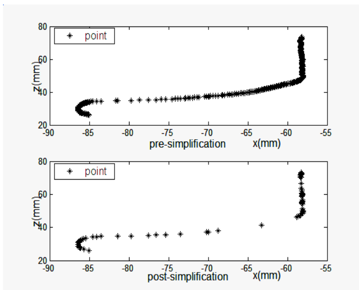


Fig.8 Sectional curve simplification, dt=0.02

Conclusion

In summary, this paper makes mathematical description of noise mechanism, and gives a corresponding mathematical model at the same time, which point data is generated by laser scanned. The whole process of laser point includes four successive methods: obvious noise removal, random filtering, smoothing data, and data compression, used to remove deterministic error, random measurement error, system error, and to simplify data in the final step. Processed to laser scan point data, is one of key technologies in surface reconstruction. The proposed method mainly aims at data scanned by laser optical knife to process. And the proposed method is applied to actual mechanical parts, and the experimental results show that principle of proposed process is clear and logical, has high computational speed, while it has advantages of good effect of noise reduction and streamlining features. Compared with single process algorithm in literature, the proposed method in this paper has more targeted to remove some kind of noise, more thoroughly to remove error data, and can simplify data according to certain compression ratio at finally step of process. The process is mainly used to two-dimensional data of cross-section line, and is also used to three-dimensional points.

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