Measurement 48 (2014) 183–186

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Calculation of profile error for complex surface

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ARTICLE INFO

Article history:
Received 26 January 2013
Received in revised form 1 November 2013
Accepted 5 November 2013
Available online 18 November 2013

Keywords:
Profile error
Linear quadtree
Rough localization
Accurate registration

ABSTRACT

Evaluation of profile error is important in manufacturing and detection of complex surface. In this paper, an algorithm is presented to calculate surface profile error accurately based on linear quadtree after rough localization and accurate registration. In rough localization, the best transformation is selected from four transformations. Then two algorithms are adopted to realize accurate registration and comparison is performed. One algorithm is the combination of LM algorithm and ICP algorithm. The other algorithm is BFGS algorithm. Experiment result shows that complex surface profile error is evaluated effectively through the proposed algorithm.

1. Introduction

Complex surfaces are widely used in aircraft, aerospace, ship building, automobile. So accuracy of measured complex surface need to be discussed. Complex surface profile measurement includes non-contact measurement and contact measurement. Most methods used in non-contact measurement are optical methods [1]. Contact measurement methods include the standard model method, the inductance measurement method, and the coordinate measuring machine (CMM) measurement method [2]. The coordinate measuring machine measurement method is often used and has high accuracy.

Surface profile error is an important representation of the surface accuracy. It is the difference between measured contour and theoretical contour. Yunfang Chen adopted particle swarm algorithm to evaluate profile error [3]. Jae-Gwan Kang defined max/min error to evaluate the distance between theoretical contour and measured contour [4]. Huang analyzed the origin of profile error [5]. Liao Ping applied genetic algorithm to figure profile error [6].

In this paper, complex surface data is measured with three dimensional coordinate measuring machine. Three dimensional coordinate measuring system is not identical to the theoretical coordinate system. So three coordinate measuring data need to be matched to the theoretical coordinate system. In this paper, three dimensional coordinate measuring system is initially matched to the coordinate system of theoretical surface through rough localization. Then accurate registration is performed with two algorithms. One is the combination algorithm of LM algorithm and ICP algorithm, and the other is BFGS algorithm [7]. The best transformation is selected by the comparison of two algorithms. Finally, based on linear quadtree, profile error between transformed measured data and theoretical surface is calculated.

2. Registration between measured data and theoretical surface

In order to evaluate profile error effectively, the coordinate system of measured data need to be transformed and it should be matched to the coordinate system of theoretical surface. Obtaining the best rotation matrix R and the best translation matrix T is key to the registration between the measuring coordinate system and theoretical coordinate system. Then the transformed data will be identical to theoretical surface. Evaluation function of the registration is given by

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0263-2241/$ - see front matter
http://dx.doi.org/10.1016/j.measurement.2013.11.002

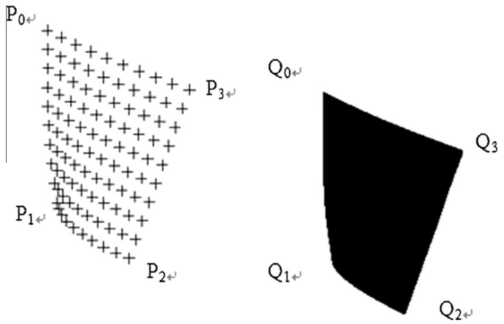

Fig. 1. Corresponding vertexes.

$$F(R,T)=\frac{1}{N}\sum\nolimits_{i=0}^{n}\|P_iR+T-Q_i\| \quad (1)$$

when function F is the minimum, the best space transformation is obtained. N is the number of measured data. P_i is the measured point. Q_i is the perpendicular foot from P_i to theoretical surface.

2.1. Rough localization

Three dimensional coordinate measuring system does not overlap the theoretical coordinate system. Measured data will be closer to theoretical surface by rough localization. Fig. 1 shows corresponding vertexes of three dimensional coordinate measuring data and theoretical surface. Four vertexes of measured data are P_0, P_1, P_2 and P_3. Four vertexes of theoretical surface are Q_0, Q_1, Q_2 and Q_3.

The steps of rough localization are as follows:

(1) One unit vector is composed of P_0, P_1 and P_2. The other unit vector is composed of Q_0, Q_1 and Q_2. These vectors are given by

$$v_1=\frac{\overline{P_1-P_0}}{|P_1-P_0|}\quad v_3=v_1\times\frac{\overline{P_2-P_0}}{|P_2-P_0|}\quad v_2=v_3\times v_1$$

$$v_1'=\frac{\overline{Q_1-Q_0}}{|Q_1-Q_0|}\quad v_3'=v_1'\times\frac{\overline{Q_2-Q_0}}{|Q_2-Q_0|}\quad v_2'=v_3'\times v_1'$$

v_1, v_2 and v_3 constitute a right hand coordinate system and unit vector is represented by $[v]=[v_1\quad v_2\quad v_3]^T$. v_1', v_2' and v_3' also constitute a right hand coordinate system and unit vector is represented by $[v']=[v_1'\quad v_2'\quad v_3']^T$. The transformation relation between any point P_i of measured data and the corresponding point Q_i is:

$$Q_i=RP_i+T \quad (2)$$

Because $[v]$ and $[v']$ are both unit vectors, $[v']=R[v]$. So the rotation matrix is given by

$$R=[v'][v]^{-1} \quad (3)$$

Substitute P_1 and Q_1 into Eq. (2), the translation matrix T is obtained.

$$T=Q_1-[v'][v]^{-1}P_1 \quad (4)$$

Then evaluation function F_1 of measured data and theoretical surface is obtained by Eq. (1).

(2) One unit vector is composed of P_0, P_1 and P_3. The other unit vector is composed of Q_0, Q_1 and Q_3. The rotation matrix R, the translation matrix T and evaluation function F_2 are obtained according to the first step.

(3) One unit vector is composed of P_0, P_2 and P_3. The other unit vector is composed of Q_0, Q_2 and Q_3. The rotation matrix R, the translation matrix T and evaluation function F_3 are obtained according to the first step.

(4) One unit vector is composed of P_1, P_2 and P_3. The other unit vector is composed of Q_1, Q_2 and Q_3. The rotation matrix R, the translation matrix T and evaluation function F_4 are obtained according to the first step.

(5) The evaluation function minimum is obtained through comparing F_1, F_2, F_3 and F_4. Thus the best rotation matrix R and the best translation matrix T corresponding with the evaluation function minimum are obtained in rough localization.

2.2. Accurate registration

After rough localization, two algorithms are adopted to finish accurate registration and the results are compared. One of the algorithms is the combination of LM algorithm and ICP algorithm. LM algorithm has fast convergence in the beginning and slow convergence in the later stage. So the algorithm adopts LM algorithm in initial stage. After iterations, ICP algorithm is used to obtain the best transformation in the later stage. The other algorithm is BFGS algorithm.

3. Profile error calculation

After measured data is matched to theoretical surface, profile error is calculated. Profile error is the minimum distance between two offset surfaces of theoretical surface containing measured data (see Fig. 2).

The mathematics model of profile error is given by

$$E=\min(\max(|d_i|+|d_j|)\quad|i,j=1,2\cdots n) \quad (5)$$

where d_i is the positive distance from P_i to theoretical surface and d_j is the negative distance from P_i to theoretical surface.

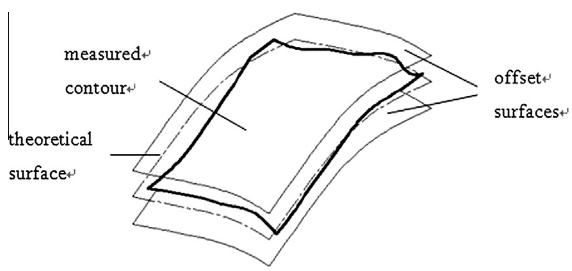

Fig. 2. Measured contour, theoretical surface and offset surfaces.