Proceedings of 10th International Conference on Precision, Meso, Micro and Nano Engineering (COPEN 10)
December 07 – 09, 2017, Indian Institute of Technology Madras, Chennai – 600 036 INDIA

Adaptive Contour Curve Based Sampling Strategy of Free-form Surface Evaluation Using Coordinate Measuring Machine

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Abstract

In modern manufacturing, coordinate measuring machine is important measuring device for evaluation of products whether they are within the desired accuracy or not. The procedure is collecting sample point (discrete point) from the surface, fitting the cloud point to that best describe geometry surface, convert the constructed surface into dense cloud, align the dense cloud to CAD model and compare for form deviation. In coordinate measuring machine discrete point measurement has a trade-off relation between the sample size and form deviation, increasing sample size results decrease in form deviation but inspection cost increase. So to get the optimal result a good sampling strategy, which minimize the measuring time and achieve the desired accuracy is required. In this work, surface contour curve based adaptive sampling strategy is proposed. The optimal number of slicing plane used for surface contour curve generation is automatically generated from the surface radius of curvature and slicing error. To generate the sample point, contour curves are segmented based on their length. Comparison is made to verify the effectiveness and robustness of the method.

Keywords: Adaptive Sampling Strategy, Coordinate Measuring Machine, Free-form Surface, Surface Contour Curve.

1. INTRODUCTION

Free-form surfaces are surfaces that don't have an axis of rotational symmetry and complex in shape [1]. These surfaces have a wide application such as in die and mold manufacturing, plastic manufacturing, automobile, aerospace, and in advanced technology such as biomedical etc. [2]. Free-form surfaces have properties like good ergonomics, aesthetic and functionality [3], due to this reason the application of free-form surface is increased from day to day. Evaluation the quality and accuracy of such surface is the current issue. Free-form surface can be evaluated using coordinate measuring machines (CMM), which the discretized data points are found in (xyz) form relative to the machine coordinate frame or the part coordinate frame [4]. The discrete data of the free-form surface is acquired through non-contact or contact (touch trigger probe) method, the non-contact method can gather up to forty thousand data point in second but the resolution is less as compare to the touch trigger method and costly, to the reverse the touch trigger probe method is very slow as compare to the non-contact method. Finding the critical sample points of the surface and measuring using touch trigger probe measuring machine, better result can achieve as compare to non-contact [5].Touch trigger probe coordinate measuring machines have high initial cost and old measuring machine, therefore, it is necessary to enhance the performance of these machines to make competitive with the modern inspection technologies. One of enhancing mechanism of this CMM is reducing the sample size of surface under evaluation by measuring the critical sample points, indirectly reduce the measuring time and cost of inspection at optimal form deviation for user define tolerance.

Generally, sampling strategies are divide in to three main categories blind, adaptive and manufacturing signature based sampling strategies, Adaptive sampling is an iterative sampling strategy, sample size is flexible and determined during evaluation processes. Since sampling strategy is based on sample size and location of samples, different sampling strategy gives different result for the same surface [6] so still, good sampling strategy is required.

Contribution of this paper is sample size and locations of sample points can be determined easily from the novel method CAD based surface contour. Script is written that automatically generated the contour curve samples on the surface based on the radius of curvature and slicing error. More over the sampling strategy is easy to implement in shop floor for practical measurement.

2. TOOLS FOR EVALUATION OF NURBS FREE-FORM SURFACE

2.1 Contouring of Free-form Surface

In this work, NURBS free-form surface is used as described in [7, 8] to investigate the proposed sampling strategy. Complexity analysis like Gaussian curvature and Mean curvature is used as described in [9].

A contour line is one of the spatial analysis sectional lines that describe the geometric feature of the physical object. This contour line shows us not only the hill and the valleys but surfaces with same elevation and change in slope of this surface. Especially when the slop of the surface hill increasing the distribution of this contour curves is close to each other and when the slop of the surface decreases the sectional contour curves are dispersed. In actual manufacturing, maximum form deviation mostly occurred around the region with more curvature. So the dense occurrence of the contour curve around the high curvature location helps us to concentrate the sample on this region. The overall process of surface contouring is shown below in Fig. 1. First, attempts to extract sectional contours curves from the 3D CAD model. The 3D model slicing thickness along the two point's direction (*P1* and *P2*) at a distance of *L* is *D* [10]. From the slicing thickness, optimal number of sectioning plane (*N*) for the given surface which is used to create the contour curve is produced.

The Contour curve generated is segmented in to number of segments using interpolation technique based on their length and the point which is used to connected each segment is consider the sample points of the surface.

ISBN: 978-93-80689-28-9

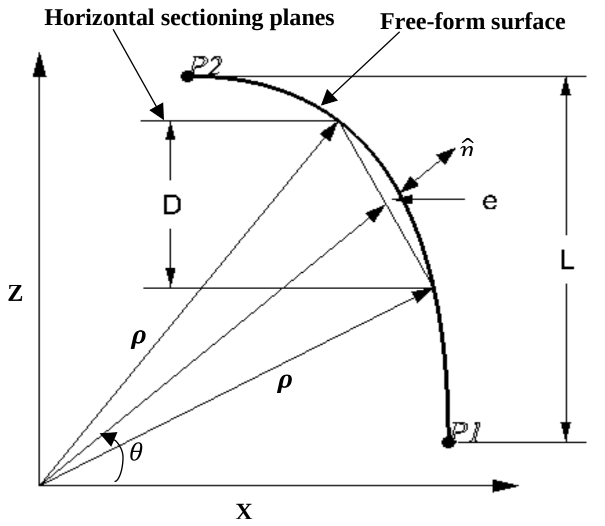


Fig. 1. Concept of contour curve generation based on radius of curvature

$$L = P2 - P1 \quad (1)$$

$$\rho^2 = (\rho - e)^2 + \left(\frac{D}{2cos\theta}\right)^2 \quad (2)$$

$$D = 2cos\theta\sqrt{2\rho e - e^2} \quad (3)$$

$$D = \frac{L}{N-1} \quad (4)$$

Where: *L* overall model height of surface, *P1* and *P2* the two extreme points on the surface, *D* is the gap between the parallel cutting planes, *ρ* radius of curvature.

2.2 Free-form Surface Forms Deviation Calculation and Inspection Uncertainty Analysis

Before form deviation of the surface is evaluated the sample point should registered to the CAD model and in this paper, the iterative closest point registration (ICP) method is used [11]. Form deviation of the freeform surface is measured by comparing of the measured surface (actual) to the design (nominal) surface using the method explained in [12]. Measurement result doubt can be quantify using Uncertainty. As the number of measurements increase, the better the estimate you will have of the 'true' value. Estimation of task-related uncertainty is likely to arise ISO 15530[13]. To check whether the measurement true or not Type A uncertainty analysis of the adaptive method is very important. In this research, the Type A uncertainty of measurement is evaluated for *n* repeated measurements of each sampling strategy, and the average form deviation of equi-parametric sampling strategy relative with dense sample (100 sample points) is our true form deviation of the surface. The statistical analysis of standard deviation and uncertainty of the inspecting results obtained from *n* repetitive measurement data is computed as method used in [14].

3. METHODOLOGY OF THE EXPERIMENT

Free-form surface contour is generated by parallel plane slicing principle along normal direction perpendicular to horizontal plane on CAD model once. The remaining sample point is added iteratively based on the maximum Gaussian curvature patches. For detail clarification, we express the procedure that we follow through below flow chart in Fig. 2.

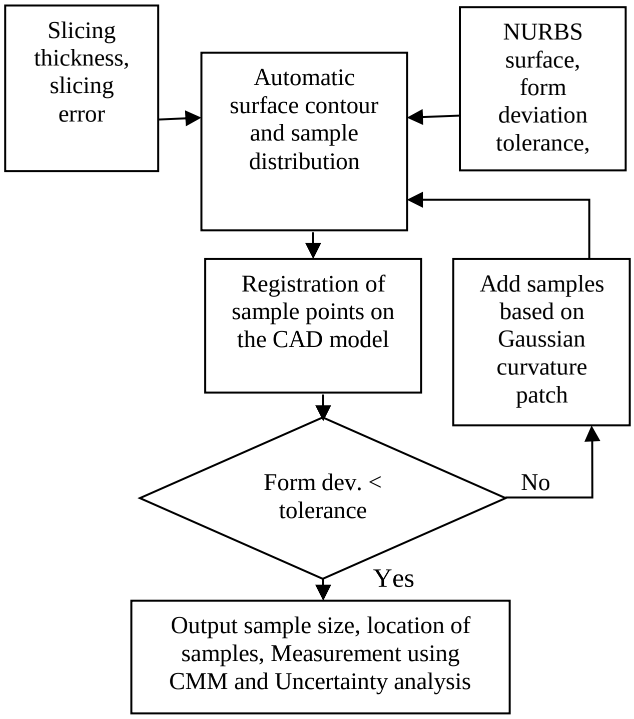


Fig. 2. Flow chart methodology of the work

4. EXPERIMENTAL RESULTS AND DISCUSSION

After sampling is done on the CAD model the actual surface is measured by MITUTOYO: a model of Crysta-plus M544 CMM, TP200 probe and stylus diameter of 2mm. Measurement is taken in protected environmental at temperature of 20±0.2^{0}c, based on the CMM standard accuracy. Models are made up of Aluminum alloy (Al-6061) surface size of 100mmx100mm. The user define tolerance is assumed ±0.5mm. Form deviation is maximum near to the critical area which is can be identifay using Gaussian curvature analysis model. Patches are created based on the maximum Gaussian curvature model as shown Fig. 4. Once the contour curve of the surface created and discreted into sample point, measurement is done to evaluate the form deviation. If the form deviation is above the defined tolerance, samples points are added depend on the maximum Gaussian curvature patch of the surface. Each patches assumed have equal curvature, and sample points are allocated depending on the size of the patches. The samples points are added in each patch randomly as compare to the large patch size. The number of sample added at the time is depend on the assumition of the large patch sample size. In this paper, the sample size added at a time is 11 which is the sum of each patch of sample size. To evalute the efectivness and roubstness of the method, measurement is repeated 50 times for each sampling strategies and the uncertainty Type A is calculated. The sample size determined from the adaptive sampling srategy is not enough to evalute the whole surface due to finite sample size, so constructed surfcae is converted into dense cloud points, 535 and 502 cloud points equi-parametric sampling strategy and the adaptive respectively for further form deviation calculation.

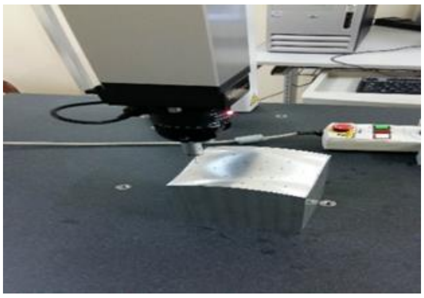


Fig. 3. Discrete sample point measurement using M544 CMM

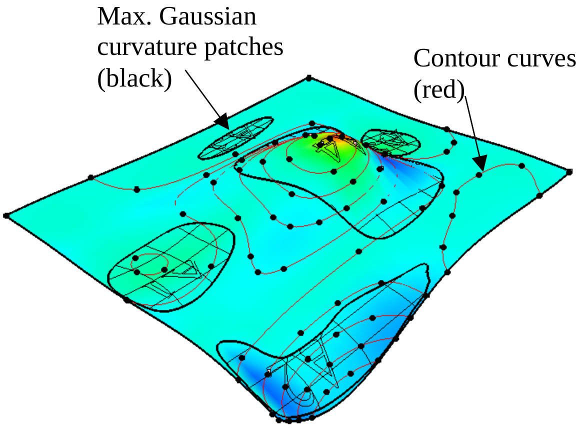
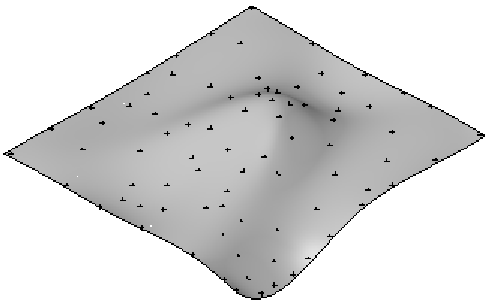
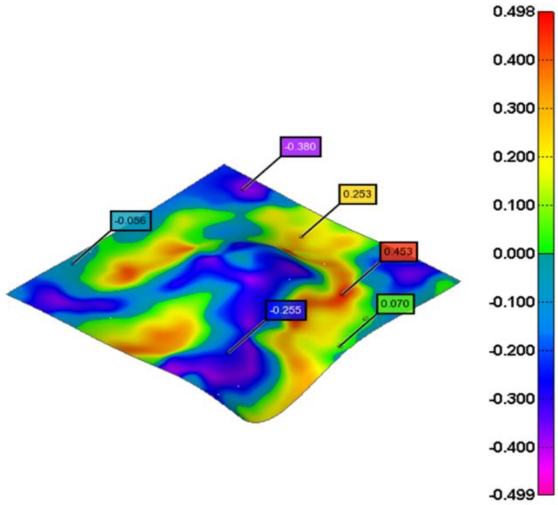


Fig. 4. Concept of maximum Gaussian curvature surface patches and surface contour

A1=524.82mm^2, A4=1604.87577mm^2, A3=158.45mm^2, A2= 616.63mm^2, A5=198.144mm^2, AT=10,000mm^2 the remaining area is surface which is not critical. Assume A4=5 samples, the remaining patches have a share of A1=5*524.83/1604.87≈2 samples,A2=10*616.637/1604.87≈2samples,A3=10*158.46/1604.87≈1sample, A5=10*198.144/1607.87≈1 sample.

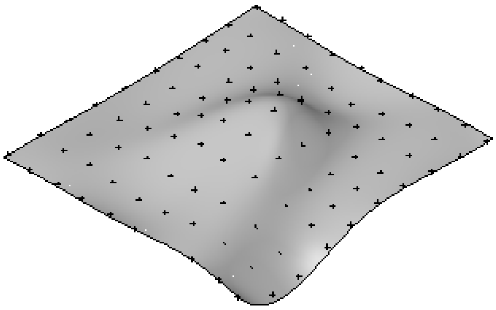


(a)

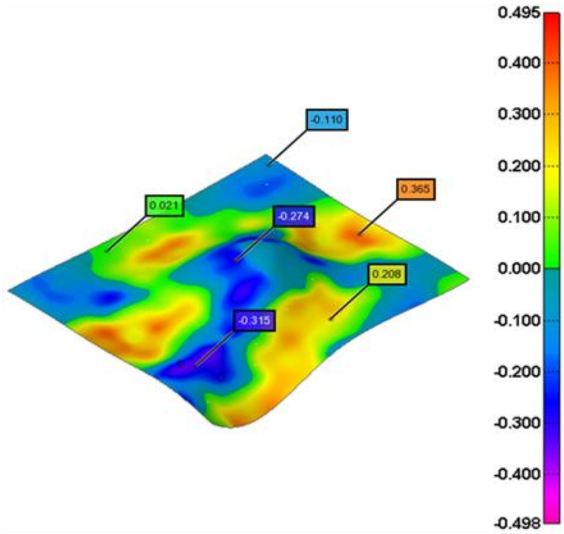


(b)

Fig. 5. (a) Adaptive contour sample distribution (b) corresponding Surface form deviation



(a)



(b)

Fig. 6. (a) Equi-parametric sampling sample distribution sample size 10*u*x10*v* (b) corresponding Surface form deviation

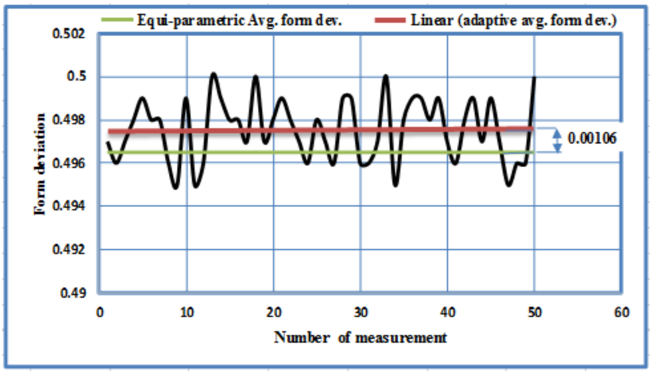


Fig. 7. Adaptive method form deviation distribution relative to equi-parametric

Table 1: Comparison of the two sampling strategy

Sampling strategy	Adaptive	Equi-parametric
Tolerance(mm)	±0.5	±0.5
Sample size	80	100
Avg. form dev. (mm)	0.497	0.4965
Global form dev. (mm)	0.498	0.498
Std. Dev.	0.0018	0.0016
Type A uncertainty	0.0043	0.0041
Measuring Time(second)	180	230
Pts within +/-(1 * Std. Dev.)	65 (81.25%)	75 (75.269%)
Pts within +/-(2 * Std. Dev.)	75 (93.750%)	92 (92.473%)
Pts within +/-(3 * Std. Dev.)	78 (97.500%)	98 (97.849%)
Surface Out of Tolerance	0.00%	0.00%

Before we start analysis the form deviation the data point clouds are generated from constructed surface the procedure is Triangular meshed free-form surface is constructed from sample points then converted into dense polygonal mesh finally the dense mesh is converted into dense cloud point. From the above Table 1 adaptive sampling strategy, 97.5% (78/80 samples points) of the samples are within ±3* standard deviation (Std. Dev.) and the same for equi-parametric 97.849% (98/100 samples points). Standard deviation is more in equi-parametric sampling strategy as compare to the adaptive method due to high form deviation on the high curvature region. Table 1 shows that no surface out of our tolerance the same to the adaptive method.

5. CONCLUSIONS

From the above Tables 1 and form deviation of Fig.5(b) and Fig.6(b), we summarized that the sample size is reduce using our method for the same NURBS free-form surface by 20% (80 adaptive and 100 equi-parametric sampling strategies) for the same accuracy (global form deviation 0.498mm). Measuring time is reduced by 40 seconds. Generally, the adaptive method is effective as compare to the equi-parametric sampling strategy which is the difference between the two sampling strategy averages form deviation is 0.00106 on Fig. 7 and robust since form deviation distribution of the adaptive method on Fig. 7 is in the range of ± 0.006. Above all, it is very easy to use in the shop floor level and applied by any professional.

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