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Isoparametric line Sampling Strategy for Evaluation of Lower Degree Free form surface using Contact Measurement

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Abstract

In modern manufacturing freeform surface are investigated using discrete sample points, but this sampling strategy has trade off relation between number of sample and form deviation. Researches evaluate free form surface using method Isoparametric line sampling strategy, but there is no paper which states that whether the method is convenient for lower degree free form surface evaluation or not. In this paper, the impact of Isoparametric line sampling strategy on lower degree of free form surface is analyzed. Samples are iteratively gathered from the surface of free form surface and compare for form deviation.

Key-words: Freeform surface, Coordinate Measuring Machine, Isoparametric Line Sampling Strategy.

1. INTRODUCTION

Lower degree freeform surfaces are surface below degree order of three(such as plane surface ruled surface) and this type of surfaces have wide application in industries such as home utensils, automotive bodies, consumer goods, mobile accessories. Industries to be competitive quality and cost of products are the main factors. In lower degree free form surface measurement coordinate measuring machines (CMM) is one method measuring the freeform using discrete points. But CMM has a tradeoff relationship between the numbers of samples and form deviation, In view of this, the location and sample size is important. The final measured form deviation of the freeform surface causes by various sources like machining error, measurement error, alignment error etc., which cause undesirable deviations from the actual free form surface and this errors can be evaluate using coordinate metrology to test the conformity of the physical object to its CAD model [1]. The measurement data can be acquisition whether in the discrete point data using mechanical contact probes such as coordinate measuring machine (CMM) touch probes or using scanning method are widely used in practical applications. CMMs with touch triggered probes can provide high measurement accuracy at the sub-micron level. However, the measurement speed is much lower than the scanning method. A scanning system can acquire thousands of data points over a large spatial range at a time [2]. But the resolution of the measured data point is relatively low [3]. Therefore, in practical applications, using one of the techniques means that the user has to suffer its limitations. The CMM with touch triggered technique involves determining the coordinate values of the measurement points located on the surface of the analyzed object. As a result, a set of discrete data in the form of coordinate measurement (sample) points is obtained. When using CAD/CAM techniques, an essential aspect of coordinate measurements is to provide relevant digital data concerning the geometry of the workpiece [4]. Sampling of the surface using coordinate metrology the number of measuring points that accurately represent the surface and the distribution of those points is the important [5]. Many papers published on sampling strategies of CMM measurements but most of them are very difficult in practical application to the shop floor level to implement on actual enviroment. Generally, sampling strategy is classified into three categories: blind samplings, adaptive sampling and manufacturing signature based sampling. The blind sampling strategies those don’t consider the complexity of the objects to be measured include uniform, random, Fan and Leut[6] They proposed featured based inspection planning and integrate a personal computer directly from CAD modelling of the surface model of an object. Measuring points generated automatically on the surface. Using method of swept-volume analysis they prevent the probe collision, they also develop simulation program for visualizing on the computer screen the probe movements along the inspection route. Prakasvudhisarn and Raman[7] They have constructed a framework for the study of cone feature measurement through an integrative investigation of data sampling and form fitting. They study in depth Sampling issue, path detection, and fitting of form zones, at the same time form verification and detailed experimental analysis is conducted to verify their methods. They used the three blind sampling strategies, Hammersley, Halton-Zaremba, and Aligned Systematic; at various sample sizes using sampling theory and prior work in two-dimensional sampling. They develop the statistics of the form deviation in Linear and nonlinear form deviations using optimization and least-squared methods and solved to yield competitive solutions. Rocco et al.,[8]proposed adaptive sampling strategy for geometric tolerance verification. The adaptive method is deterministic in nature to avoid this they developed statistical adaptive plane where their prediction is depend on the kriging model which is used to select the position of the next sample point. Based on the above principle they develop an algorithm that predict the next point position on the line. The adaptive method is compared with the pure Latin Hypercube sampling strategy and the result shows that adaptive achieved 100% accuracy for fifty sample points while the pure Latin Hypercube stops at 65%. Luca and Paul[9] Introduced a sampling strategy based on B-wavelets shape decomposition, then proposed to detect the points of interest that reflect the variations in different levels. The Discrete wavelet transform is used to obtain the curvature information of a signal. The samples are then allocated according to the curvature distribution in different regions. The method has been tested with other common sampling methods and in different test cases. They get better result when the reconstructed shape is profile. For surface with abrupt change also perform well. If the analyzed surface has slow changes, the area based parameterization ensures a better reconstruction error if the sample size is small. They have taken into account the value of differential property, such as the curvature of the B-wavelets curves or surfaces at different levels. Keqing L. and Wen [10] introduce a novel adaptive sampling approach for digitizing unknown free-form surfaces based on advanced path detecting and the sampling efficiency and accuracy improved. Manufacturing signature based sampling strategy, Colosimo et al.,[11] new approach for selecting the optimal locations of the points for any given sample size based on estimating the “manufacturing signature” i.e. is tolerance interval based(TIB), that is the systematic pattern left by the manufacturing process on the machined items. The proposed approach is based on using regression for estimating the manufacturing signature and then selecting the measurement point locations. The strategy tends to concentrate sampling points in those zones that, according to the model of the signature, depend on the maximum deviation of points from the ideal geometric feature. They concluded that choice of sampling points causes geometric error estimate to be more repeatable and less biased, so lower uncertainty is expected.

In this paper, the impact of Isoparametric line sampling strategy on lower degree of free form surface is analyzed.

2. MATERIALS AND METHODS

The sample points are distributed using Isoparametric line sampling strategy, sample solid models are developed and machined by 3-axis milling machine the rest step is explain as follows;

1. Two NURB higher degree free-form surface are generated by solid works software S1 (u, v) and S2 (u, v) Fig. 3.

2. NC code generated using Master Cam X9 (trial version) and surfaces are machined by vertical CNC milling machine.
3. N numbers of sample points are distributed using Isoparametric line sampling strategy.
4. Measuring the surface using coordinate measuring machine from the free-form surface.
5. Fitting of the cloud point data onto the surface by using Cloud Compare V2.8 software.
6. Measure the deviation between the nominal surface and actual surface or measured point (point cloud) using Cloud Compare V2.8 software.
7. Check the deviation whether within tolerance or not, otherwise increase the Isoparametric lines.
8. The obtained point set N used for guiding the CMM measurement of freeform surface.

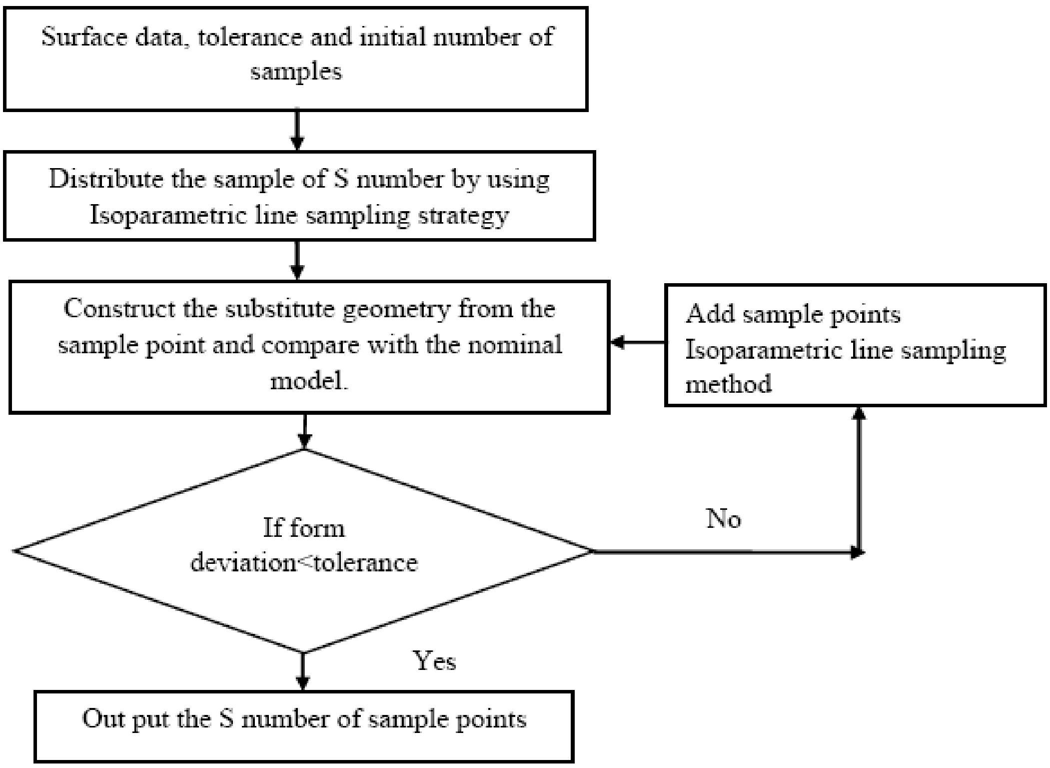


Fig. 1. Flow chart of modified sampling strategy of the proposed method

2.1 Free-form NURBS Surface

Freeform surfaces mostly described using parametric surface representations [12]. Parametric surfaces such as NURBS (Non Uniform Rational B-spline), Bézier, and B-spline are common surfaces that used for freeform surface modeling. Freeform surface can be representing by parametric and non-parametric equation. NURBS surface of degree p in the u direction and degree q in the v direction is a bivariate vector–valued piecewise rational function of the form;

$$S(u,v) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} N_{i,p}(u) N_{j,p}(v)\omega_{i,j} P_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} N_{i,p}(u)(u) N_{j,p}(v)\omega_{i,j}} \qquad 0 \le u,v \le 1 \tag{1}$$

Where the $\{\boldsymbol{P}_{i,\,j}\}$ are the bidirectional control point, $\{\omega_{i,j}\}$ are the weights, and the $\{N_{i,p}(u) and\ N_{j,p}(v)\}$ are the non-rational B-spline basis function define on the knot vector

2.2 Isoparametric Line Sampling Strategy

In e Isoparametric line sampling strategy, sample points are distributes on the isoparametric line through interpolation as shown in Fig.2 below. First the isoparametric lines are generated on the surface using parallel plane intersection with the free form surface then curves are interpolated to create the sample points. As compare to the other sampling methods it is easily to implement on NURBS surfaces. Isoparametric line is under the category of curvature based sampling strategy and insensitive to surface complexities such as sharp curvature changes and unequal surface-patch sizes [13].

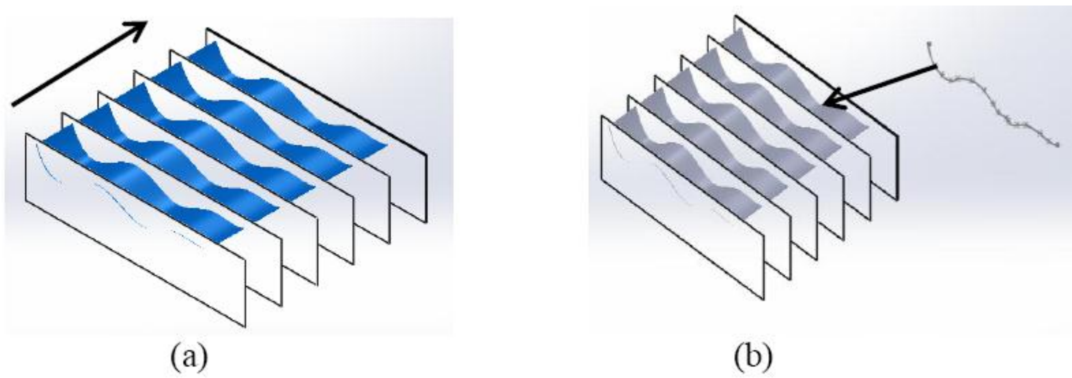


Fig. 2 (a) Isoparametric lines sampling strategy intersection planes model 1
(b) The intersection isoparametric curves model 1

2.3 Free form Surface Form Deviation Calculation

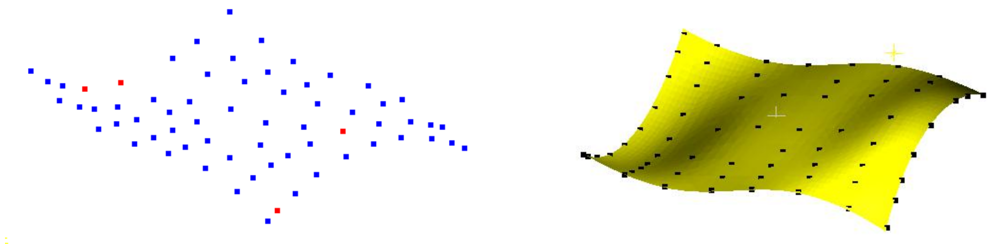
Prior calculation of the surface form deviation, it should fit the measurement data to the nominal surface and maximum surface deviation is assumed to be ±0.1mm depending on the user define tolerance. Uncertainty of the CMM is determined depending on the standard given by ISO 15530-2 of multiple strategies in calibration of artefacts. Average deviation of the actual from the nominal surface is considering the actual deviation between the surfaces. Having produced workpiece, the actual form of the surface is described as follows: An ideal (nominal) shape of the surface element can be described by the shape function *N(p)*, where *p* denotes feature variables describing the surface.

$$M(p)=N(p)+d(p) \tag{2}$$

$$d_{avg} = \frac{\sum_{i=0}^{n} \hat{n}[M(p)-N(p)]}{n} \tag{3}$$

Where: *M(p)* the actual measurement points, d_{avg} average form deviation, $\hat{n}$ normal Vector to the surface.

In coordinate measuring machine (CMM) coordinates of measurement points are sampled on the surface. Before we calculate the surface deviation the point cloud should fit to surface and in this research fitting is done by Cloud Compare v2.8[14], and the diagram below shows that the fitting processes before and after.

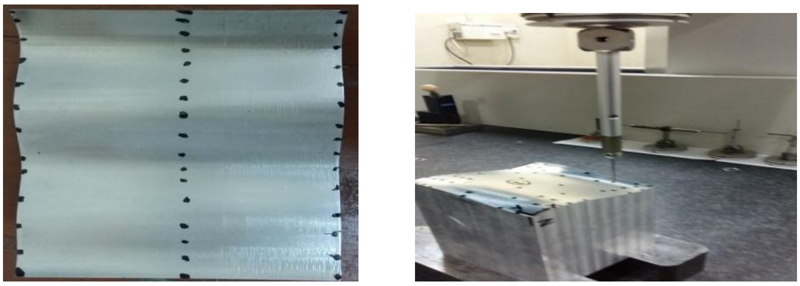


(a) (b)

Fig. 3. (a) CMM cloud data points before surface fitting and **(b)** CMM cloud data points after surface fitting

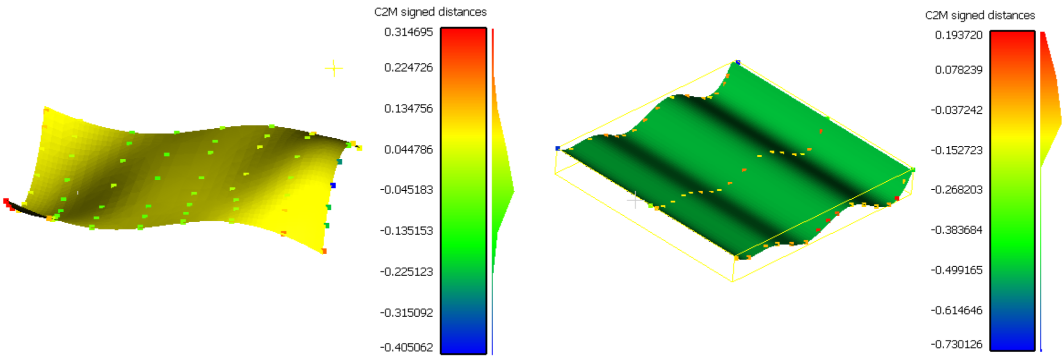
3. EXPERIMENTAL RESULT

The two models of lower degree freeform surfaces are measured by MITUTOYO: model of Crysta-plus M544 CMM at environmental temperature of 20^0c±0.2 depending on the ISO 1036-2 standard the accuracy. The maximum permissible measurement error of the machine is E=(3.5 +4.5L/1000)μm, and the samples are distributed based on Isoparametric line methods. Model surfaces are made up of Aluminum alloy (Al-6061) with dimension of 100mmx100mmx50mm machined by 3-axis vertical milling CNC machine model of VML800, spindle speed of 2000rpm with accuracy ±0.005mm. samples are distribute using Isoparametric line sampling strategy depending on the given tolerance of the surface deviation, the remaining samples are add Isoparametric line sampling strategy method.



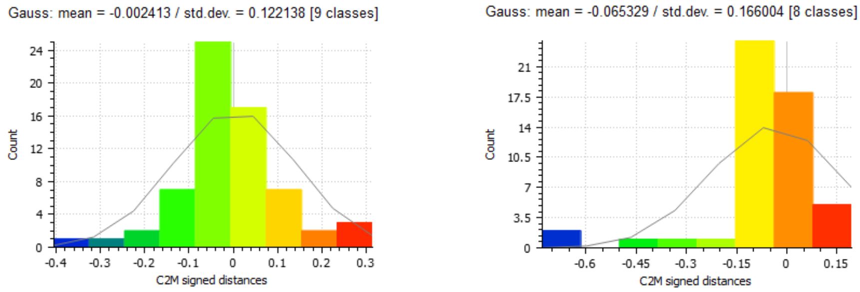
(a) (b)

Fig. 4. (a) Sample point distribution on mode 2
(b) Measuring of freeform surfaces of model 1 using CMM



(a) (b)

Fig. 5. Form deviation of free form surface (a) model 1 (b) model 2



(a) (b)

Fig. 6. form deviation gaussian distribution of (a) model 1 (b) model 2

Table 1: The inspection results for the real part

Parameters	**Model 1 (degree 3)**	**Model 2(degree 2)**
	Isoparametric line method	Isoparametric line method
Average surface form deviation (mm)	0.0024	0.065
Variance of form deviation (mm^2)	0.0149	0.0275
Sample size	65	48

4. CONCLUSIONS

The isoparametric line sampling strategy is tested on two models with degree 2 and degree 3 free form surfaces. Scatter point is created from the interpolated isoparametric line and distributed on the free form surface to evaluate for form deviation. As we can see the above Table 1 form deviation and sample size of both models are presented. It is obvious as the degree increase the sample size should increase since the complexity is increase and as sample size increase the form deviation should decrease. Model with degree 3 show good form deviation 2.4μm at sample size of 65 but model 2 degree two the form deviation is not good at optimal sample size of 48 which is 65μm this shows us that even though we use this method for lower degree is optimal and efficient the manufacturing error is the most dominant factor to surface accuracy. Generally form deviation of surface is not only depending on the measurement error but also mostly on the manufacturing error. Fig. 6 is the Gaussian distribution of the samples form deviation with respect to the mean value this result shows the form deviation is normally distributed with the good variance of variation samples form deviation, almost 1.49% rejection of the measured samples for model 1 and 2.75% of sample rejection of model 2 in model two the rejection of sample is high as compare to the model due to high manufacturing error. Overall conclusion the method is efficient and robust for lower degree surface to evaluate the form deviation.

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