SURFACE PROFILE ERROR EVALUATION PROCEDURES USING A COORDINATE MEASURING MACHINE

Sung Ho Chang
Gary D. Herrin

Department of Industrial & Operations Engineering
The University of Michigan
Ann Arbor, MI 48109-2117

Technical Report 91-10
March 1991

ABSTRACT

This paper presents the procedures to estimate surface profile error. There is no commonly accepted procedures to estimate surface profile error because the definitions of surface profile error in current standards are based on the continuous measurements. The proposed procedure are based on the prediction of the surface profile from the discrete measurements using a coordinate measuring machine. The sample sizes used in the proposed procedure are obtained by the maximum prediction interval approach. The proposed procedure tries to adopt the definition given in the standards as much as possible. This procedure is tested by simulation in two different cases.

1. Introduction

Profile error evaluation of surface with arrays of contiguous patches is different when compared to the problems that we have discussed so far. We should estimate concerned features from measurements in the previous problems, however, we already know the exact form of a concerned surface in this problem due to the existing CAD system. A profile is the outline of an object in a given plane (two-dimensional figure). Profiles are formed by projecting a three-dimensional figure onto a plane or by taking cross sections through the figure (ANSI Y14.5). With profile tolerancing, basic untoleranced dimensions are used to define the desired shape and/or relation of the toleranced feature. Where the toleranced feature is curved or irregular shaped, sufficient basic dimensions are used to describe the exact contour. The profile tolerance specifies a uniform boundary along the true profile within which all the elements of the considered surface must lie. An appropriate view or section is drawn to specify the profile tolerance. The boundary of the tolerance zone follow the geometric shape of the true profile, except at sharp corners. Where the basic contour includes a sharp corner, the interpretation is that the tolerance zone will extend to the intersections of the tolerance boundary lines. If these intersections of the tolerance zone boundaries permit an unacceptable variation in corner contour, a maximum or minimum radius may be specified for the corner of the actual part.

Our concern is evaluation of profile error of the considered surface. When the surface shape is complicated it is represented by the combination of many patches which are represented by the parametric representation in current CAD system. While we cannot get explicit single representation of whole surface, we have explicit parametric representation of each patch. Therefore, measurements should be collected patch by patch to have information about the variation of each patch. By comparing the variation of each patch to the given profile tolerance zone width, we can make a decision whether the considered surface satisfies the profile tolerance or not. When the considered surface does not satisfy the given tolerance, we can find which patch generates unexpected variation.

Then, one of the problems is that how many measurements are needed to obtain information about patch variation with a certain confidence level. Also the determination of profile error using these information is another problem. Modeling of surfaces using minimum number of points can be found in many literatures [Coons (1974), Faux and Pratt (1979), Forrest (1968, 1972), Peters (1974), Chasen (1978), Barsky (1982), Gould (1972), and Mortenson (1985)]. However, those literatures were only concerning about the construction of surfaces and were not concerning about the variation of given surfaces' profile. While sample size planing for estimation of each patch is discussed in previous chapter, we did not discuss how to evaluate profile error using these estimated patches.

Consequently, we should develop procedures to estimate profile error based on the estimated patch for two typical cases. One is the case without sharp corners and another is with sharp corners. To accomplish this task we assume that CMM coordinate system is same as the surface coordinate system which is represented in CAD database.

2. Procedures to Estimate Profile Error

2.1 Profile Error without Sharp Corners

When we assume that the deviations from the manufactured patch follow a normal distribution, we can obtain its maximum variation with certain confidence level based on the maximum prediction interval [Chang, Herrin and Wu (1990)]. From the estimated patch we can obtain two boundary surfaces which have the distance of maximum prediction interval by an approximation. Even though profile tolerances apply normal (perpendicular) to the true profile at all points along the profile (ANSI Y14.5), it is difficult to represent those boundary surfaces by explicit equations [Crampin, Guifo and Read (1985), Duffie and Feng (1985), Farouki (1985), Klass (1983)].

Now we have information about variation of the manufactured surface. However, this information does not satisfy the requirement of profile error estimation. Because the profile error is defined as the deviation from the true profile, the information about the deviation of manufactured surface cannot be treated as profile error directly. Then, we need a comparison between true profile and manufactured profile.

In comparing between true profile and manufactured profile, profile error can be estimated in three different cases. First when the true profile is between upper prediction boundary (UPB) and lower prediction boundary (LPB), the estimated profile error is same as the maximum prediction interval length (Fig. 1). Because the maximum prediction interval already considers the variation of location of the real profile, the real profile can be located anywhere between two prediction boundaries. Second, when a portion of the true profile is above UPB while the whole true profile is above LPB or vice versa, the estimated profile error is the sum of the maximum prediction interval length and the absolute maximum value of the outside of the boundaries (Fig. 2). Finally when a portion of the true profile is above UPB and other portion of the true profile is below LPB, the estimated profile error is the sum of the maximum prediction interval length and the absolute maximum values of the outside of each boundary (Fig. 3). In this procedure intersection checking is done numerically by constant interval in both directions of parameters. Therefore, smaller interval can give better accuracy. This procedure for each patch is illustrated in Figure 4.

Depending on design requirements, the tolerance may be divided bilaterally to both sides of the true profile or applied unilaterally to either side of the true profile. For each case, we can simply modify the proposed procedure to estimate profile error.

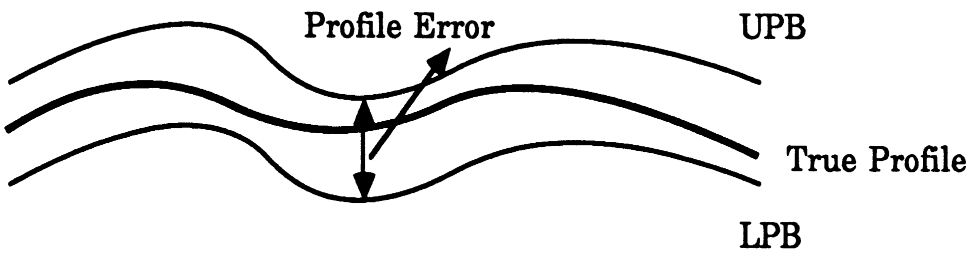


Figure 1 True Profile is between UPB and LPB

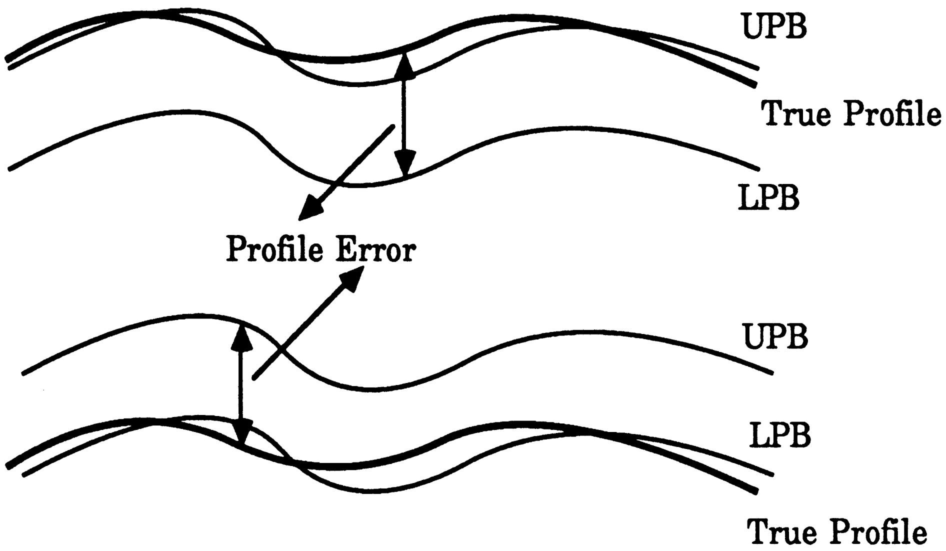


Figure 2 A portion of the true profile is outside the each prediction boundary

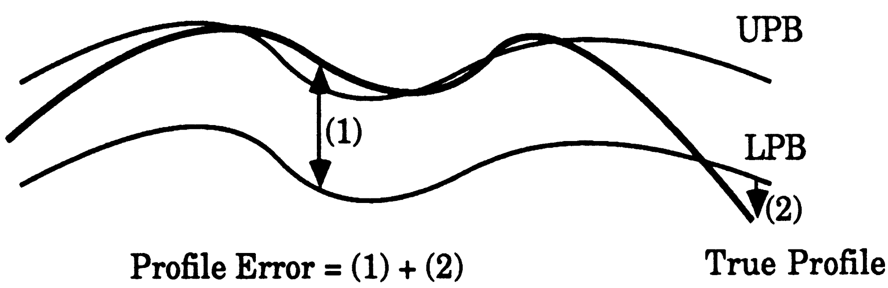


Figure 3 Portions of the true profile are outside the prediction boundaries

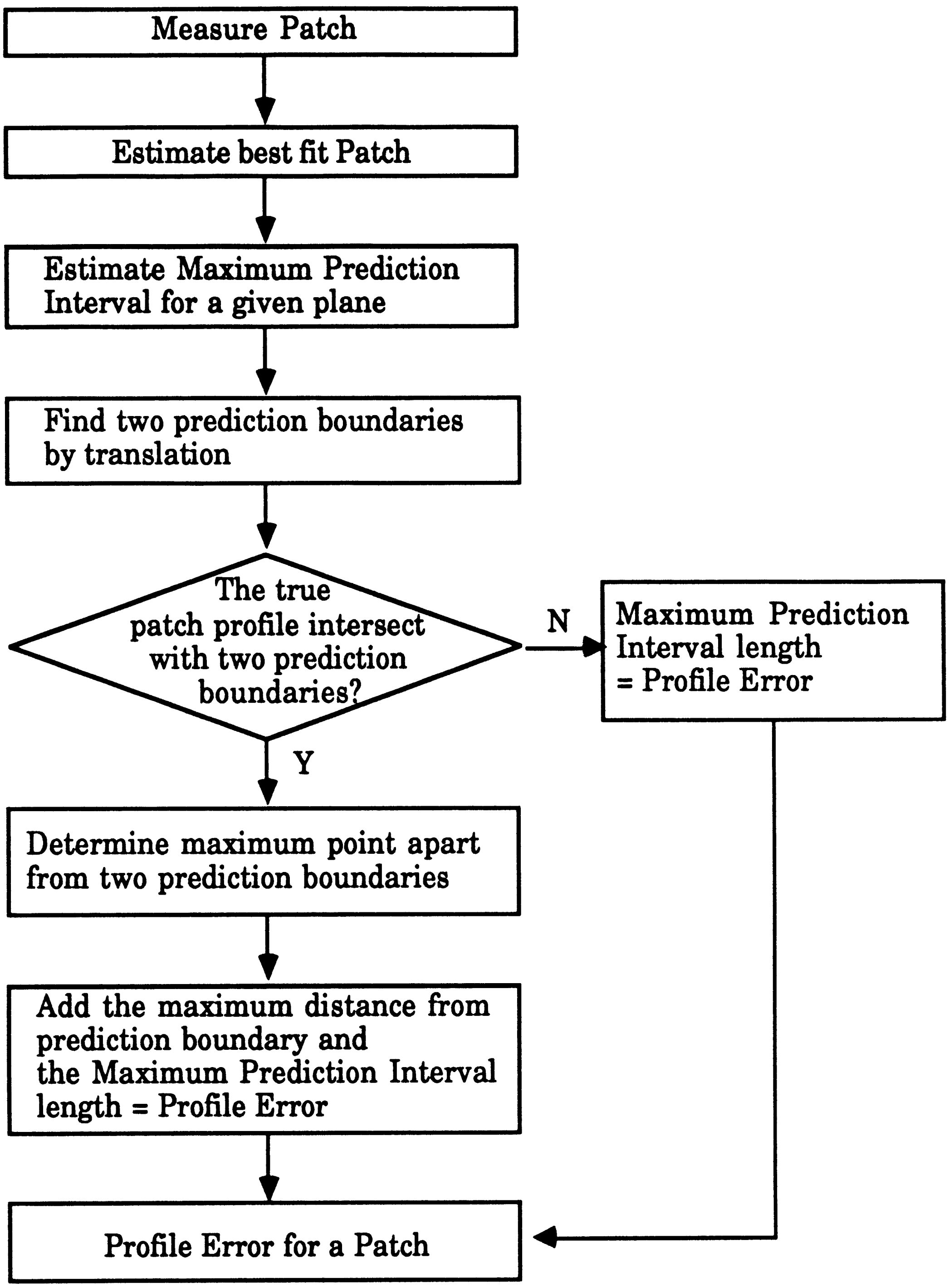


Figure 4 Procedure to Estimate Profile Error for a Patch

2.2 Profile Error with Sharp Corners

When true profile has sharp corners, the tolerance is extended to the intersections of the tolerance boundary lines (Fig. 5). Since the intersecting surfaces may lie anywhere within this converging zone, the actual part contour could conceivably be round (ANSI Y14.5). If this is undesirable, the drawing must indicate the design requirements, such as by specifying the maximum radius (Fig. 6).

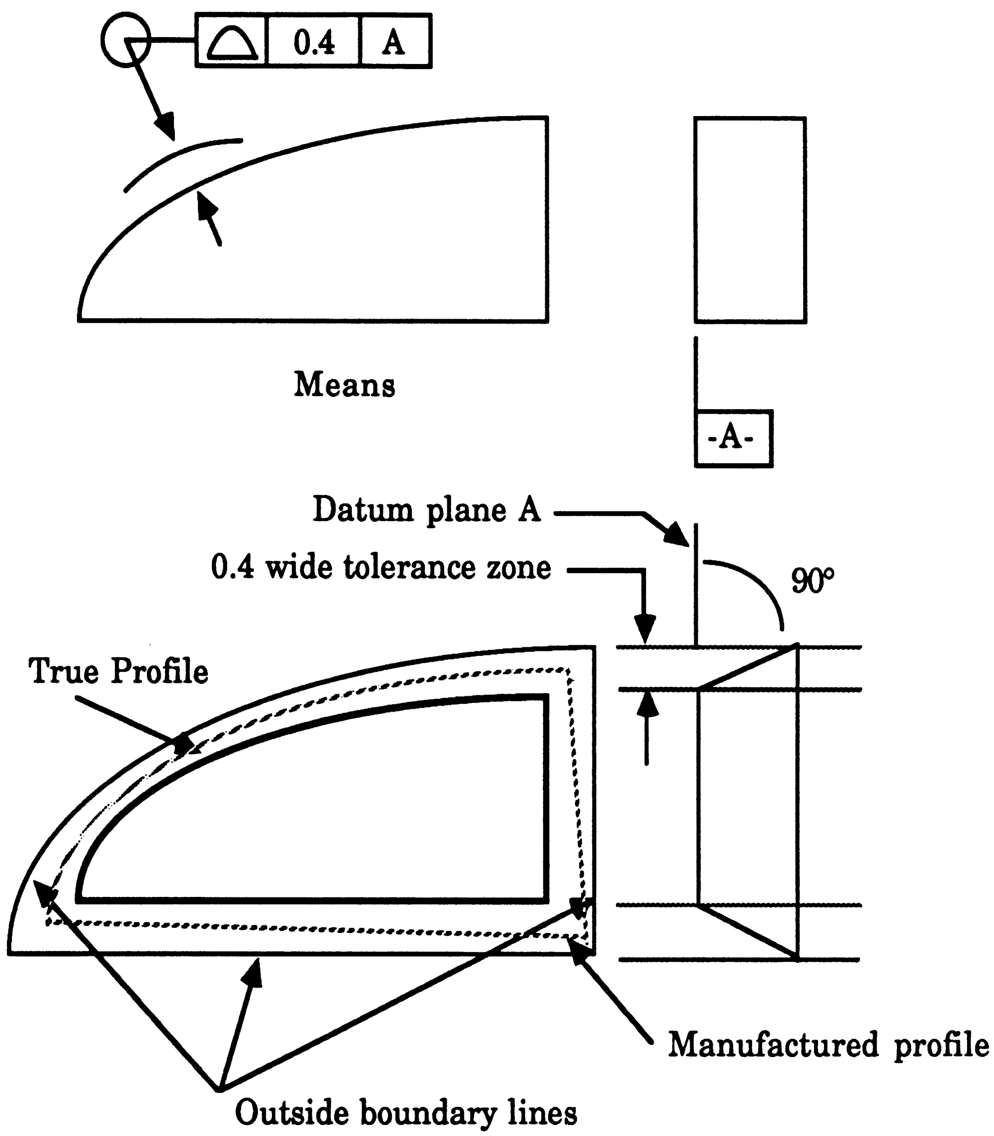


Figure 5 Specifying Profile of a Surface for Sharp Corners (ANSI Y14.5)

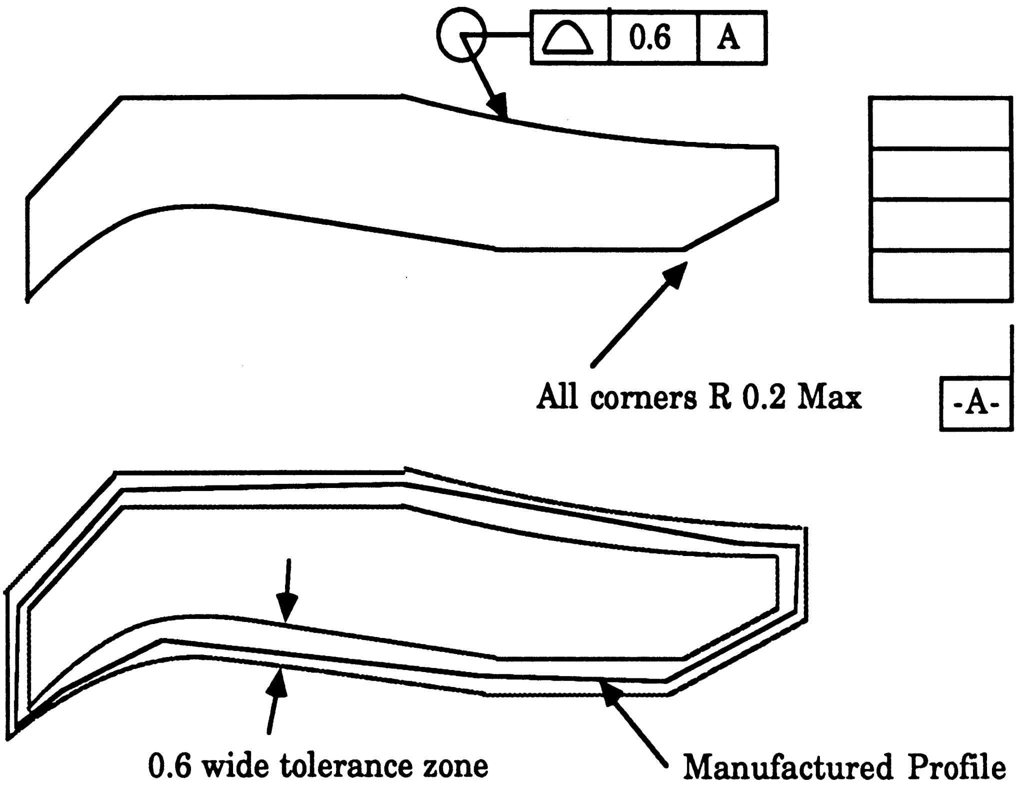
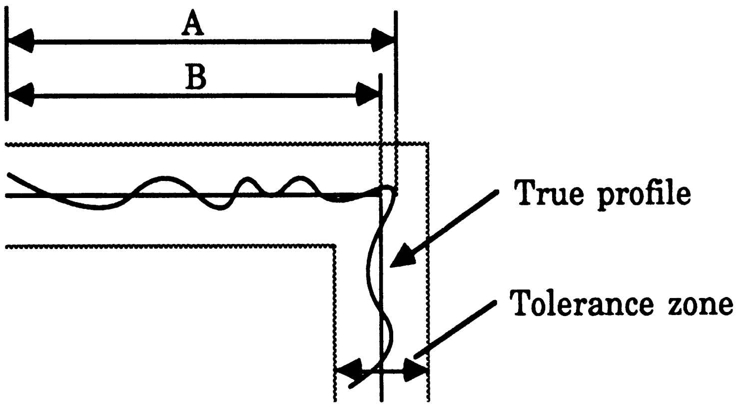


Figure 6 Specifying Profile of a Surface all around (ANSI Y14.5)

The procedure to estimate profile error at a sharp corner has no difference from previous procedure except the comparison range is extended or reduced to the measured corner point (Fig. 7).



A: Comparison range with sharp corner
B : Comparison range without sharp corner

Figure 7 Comparison Range with Sharp Corner

2.3 Simulation

Simulation study was conducted to verify the proposed procedure. Two different situations were simulated: one is the case that the true profile was inside the maximum prediction interval band and the other is the case that portions of the true profile was outside the maximum prediction interval band. For each sample size we repeated 30 times of run and calculated the mean and standard deviation of the estimated surface profile errors.

The parametric equations of the assumed CAD surface patch used in the simulation were as follow:

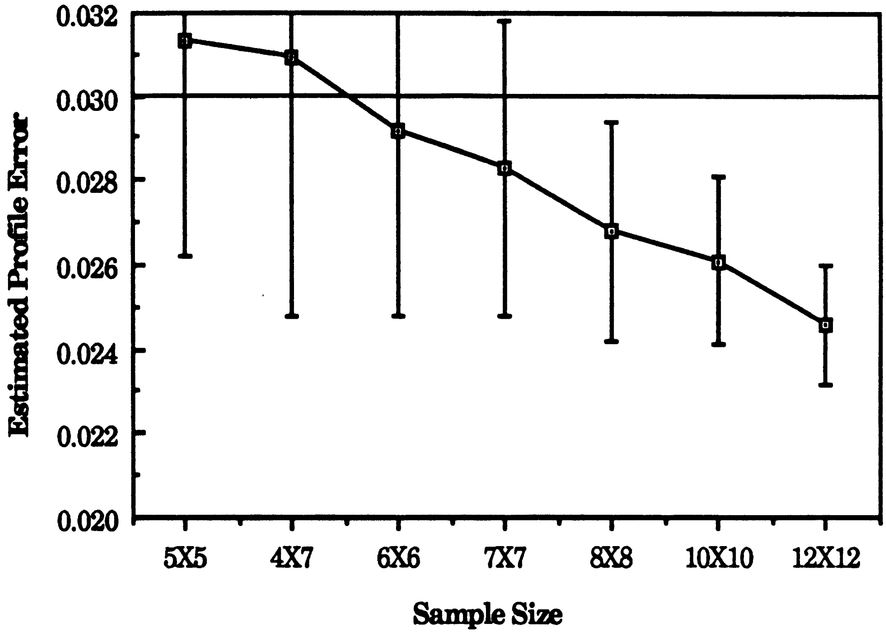
$$X(u,v) = u$$
$$Y(u,v) = v$$
$$Z(u,v) = 0.3*[\ 1 - (u+v-1)^2 + (u-v)^2\ ]$$

Normal random numbers of 2500 with mean zero and standard deviation 0.005 were generated. Those numbers were added in normal direction to the surface points sectored by 0.02 in each parameter. We assumed that real surface profile error was 0.030. We collected various sample sizes by grid type sampling and estimated manufactured surface profile. Then, we estimated the surface profile errors by applying the proposed procedure. The results were the case that the true profile was inside the maximum prediction interval band and were shown in Fig. 8. We found that the estimated surface profile error at the proposed sample sizes, 16 (4x4) for 95% confidence and 256 (16x16) for 99% confidence, was very close to the assumed real surface profile error.

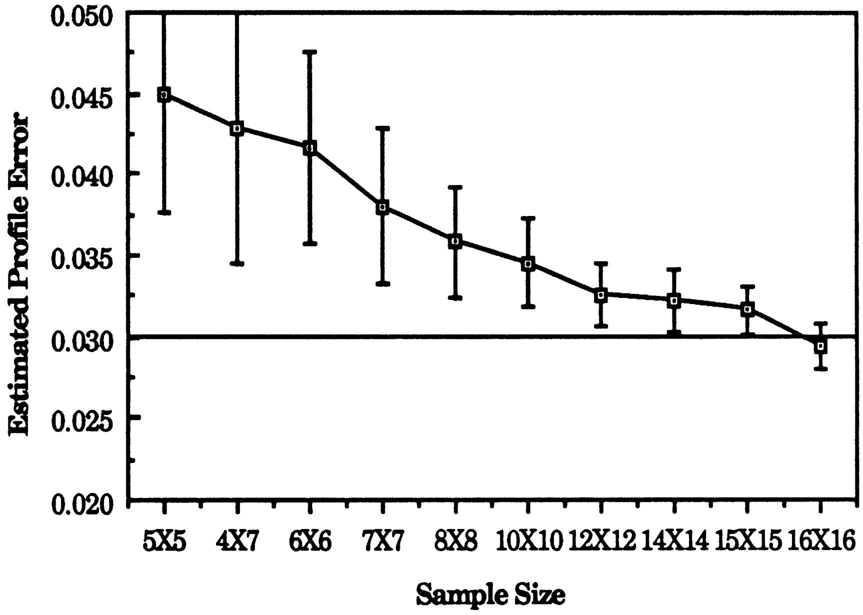
For the second case study, we shifted the normal random numbers to Z-direction by 0.007. We assumed that real surface profile error was 0.0085 (0.007+3*0.0005). Because amount of shift was greater than 3*(standard deviation of noise), we expected that portions of the true profile will be outside the maximum prediction interval band. The simulation results was similar to our expectation and was shown in Fig. 9. We also found that the results based on the proposed procedure was very close to the assumed real surface profile error.

3. Conclusion

This paper has presented procedures to estimate profile error of surface. Appropriate sample sizes and profile error estimation methods have been proposed. These procedures interpreted mathematically the definition of profile error given in current standard (ANSI Y14.5). When a precise profile estimation is required, large sample size with higher confidence level could be used. The proposed procedures could be established as a basis for a CMM practice.



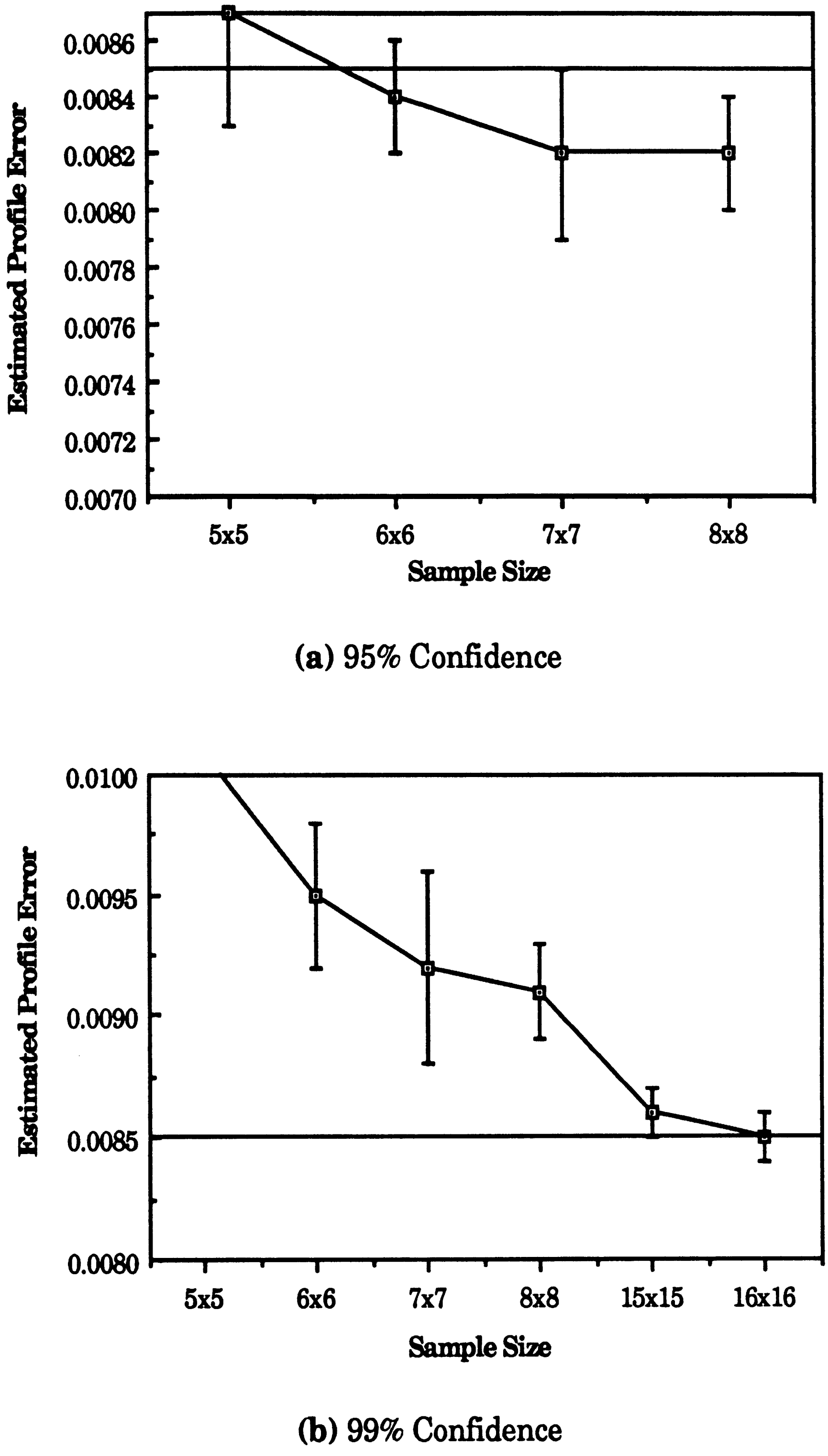
(a) 95% Confidence



(b) 99% Confidence

Note: Real Surface Profile Error = 0.030

Figure 8 Mean and Standard Deviation of Estimated Surface Profile Error with **(a)** 95% and **(b)** 99% confidence when the desired surface is Inside the Maximum Prediction Interval Zone



Note: Real Surface Profile Error = 0.0085

Figure 9 Mean and Standard Deviation of Estimated Surface Profile Error with **(a)** 95% and **(b)** 99% confidence when the portion of the desired surface is Outside the Maximum Prediction Interval Zone

References

American National Standard Institutes (ANSI Y14.5M-1982) *Dimensioning and Tolerancing.*

Barsky, B. A. and D. P. Greenberg [1982], "Interactive Surface Representation System Using a B-Spline Formulation with Interpolation" *CAD* No. 4, July.

Chang, S. H., G. Herrin, and S. M. Wu [1990], "Sample Size Planning and Estimation of Form Errors using a Coordinate Measuring Machine", *Department of Industrial and Operations Engineering Technical Report 90-35*, The University of Michigan, Ann Arbor, MI.

Chasen, S. H. [1978], *Geometric Principles and Procedures for Computer Graphic Applications*, Prentice-Hall, Inc., N.J.

Coons, S. A. [1974], "Surface Patches and B-Spline Curves", *Computer Aided Geometric Design*, Barnhill, R. E. Riesenfeld, R. F., Editors, Academic Press, NY, pp. 1-16.

Crampin, M., R. Guifo, and G. A. Read [1985], "Linear Approximation of Curves With Bounded Curvature and a Data Reduction Algorithm", *Computer-Aided Design*, Vol. 17, pp. 257-261.

Duffie, N. A., and S. C. Feng [1985], "Modification of B-spline Surface Patches Using Least-Squares Fitting Techniques", *Computational Mechanical Engineering*, CIME Research Supplement, pp. 57-65.

Farouki, R. T. [1985], "Exact Offset Procedures for Simple Solids", *Computer-Aided Geometric Design*, Vol. 3, pp. 257-279.

Faux, I. E., and M. J. Pratt [1979], *Computational Geometry for Design and Manufacturing*, Wiley, New York.

Forrest, A. R. [1968], *Curves and Surfaces for Computer Aided Design,* Doctoral Thesis, University of Cambridge.

Forrest, A. R. [1972], "*Mathematical Principles for Curve and Surface Representation*", Church College, Cambridge, March, pp. 5-13.

Gould, S. S. [1972], "*Surface Programs for Numerical Control*", Churchill College, Cambridge, March, pp. 14-18.

Mortenson M. E. [1985], *Geometric Modeling*, John Wiley & Sons.

Peters, G. J. [1974], "Interactive Computer Graphics Application for the Parametric Bi-Cubic Surface to Engineering Design Problems", *Computer Aided Geometric Design*, Barnhill, R. E. and Riesenfeld, R. F. Editors, Riesenfeld Academic Press, Inc., NY, pp. 259-302.