Modelling of Spatial Constraint in CMM Error for Uncertainty Estimation

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Abstract

Authors propose a noble simulation method applicable for estimating uncertainty in coordinate metrology. Recognizing a key point for uncertainty estimation on task specific measurement on CMM is to determine uncertainty of a single coordinate reading, a simple and effective modelling procedure to derive not only variance but also spatial covariance expressing mutual constraint between plural observation points is presented. Actual spatial constraint observed on 350 CMMs on the production floor shows good agreement with that predicted by the proposed model.

Introduction

Uncertainty analysis of CMM (Coordinate Measuring Machine) becomes important concern today. Monte Carlo simulation method is a major possibility to derive a trial value from given variance information. However since the method normally adopts a simple random number generator, plural trial values mutually constrained as result of contribution from unknown systematic component, e.g. geometrical error of CMM or probe can not be modeled directly. Typical preceding studies adopt an additional model based on randomized combination of a sort of basis functions [1-4]. The basis function can be described by Fourier spectrum, harmonics function, or sinusoidal function for example. As the result, a combination made by random trials and the other model composed by basis function builds an uncertainty contribution component with constraint. This way can be understood as modelling of variance and related covariance conforming to GUM [5]. The covariance is equivalent to auto-correlation or correlation factor naturally.

Authors proposed a simple way of modelling variance and covariance observed in geometrical deviation of CMM, such as position error, straightness error and so on [6]. Proper quantification scheme for the spatial constraint was not found at that stage unfortunately, and assumed parameters were adopted. Following study [7] proposed an idea of derivation of spatial constraint information from the template expression of the verification standard of CMM such as ISO 10360-2 [8]. It is noted that this way of modelling realizes a possibility of task specific uncertainty estimation on coordinate measurement in the maximum permissible sense.

ISO10360-2 Template and spatial constraint

According to ISO10360-2 standard for acceptance and reverification of CMM, seven independent size measurements on the material standard of size are performed in any location and/or orientation within the measuring volume of the CMM. Performance of the CMM is verified if all the measured deviation lie with in the specified range. The range may adopt a typical template expression as shown in equation (1). Increasing size to be evaluated, permissible length error enlarges correspondingly.

$$\mathrm{MPE}_E = \pm\left(A + L/K\right) \text{ and } B$$

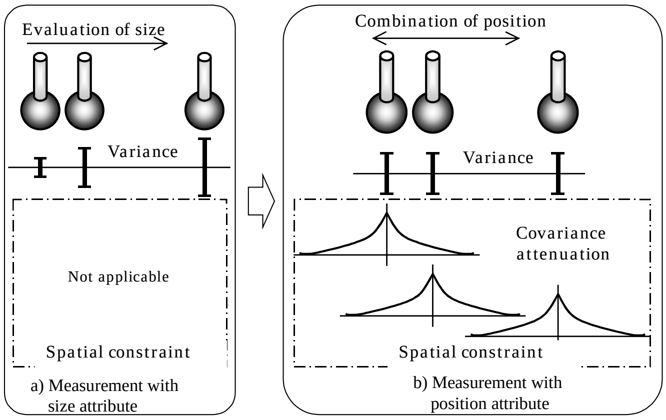


Fig. 1 Modelling of measurement uncertainty of size with spatial constraint

Recognizing the maximum permissible error range as an indirect expression of uncertainty in size meas-urement, the way of modelling is drawn in Fig. 1-a) schematically. Since verification measurement may be allocated to any location and ori-entation in the volume, a simple error model with homogeneous variance in any location and orientation of the volume is believed to be realistic. Furthermore spatial constraint between plural observation points is understood as attenuating correlation effect depending on the mutual dis-tance. This way of modelling is shown in Fig. 1–b). Note that both way of modelling leads to very similar algebraic unfolding result.

Task specific uncertainty based on model with spatial constraint

Task specific uncertainty estimation by using the proposed model with spatial constraint can be performed as drawn in Fig. 2. The method requires very limited input parameters such as ISO10360-2 specification and specific measurement strategy. Since the ISO10360-2 specification is tolerance to be satisfied always, uncertainty estimation result by the method becomes maximum permissible sense. In the other word, the method derives some over estimation in resulted uncertainty. The method may become economically beneficial estimation method if the over estimated quantity is acceptable for industry. Further study on this over estimation will be necessary.

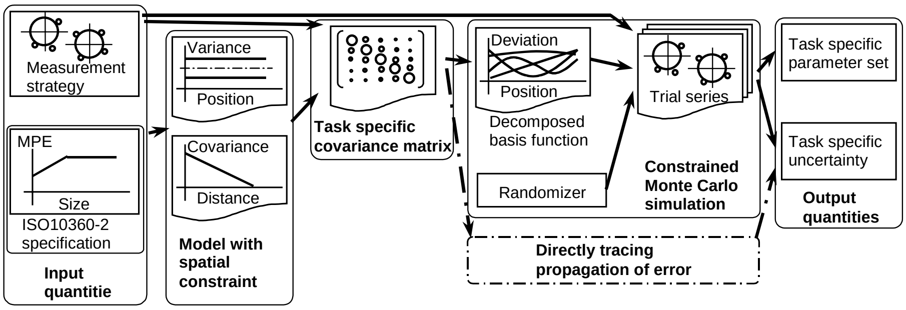


Fig. 2 Estimating task specific uncertaintybased on model with spatial constraint

The given ISO10360 -2 specification is transferred to vari-ance and covariance by the proposed model with constraint. Task specific covari-ance matrix reflecting also the given meas-urement strategy is then calculated. We need one more step to derive task specific uncertainty according to GUM. That is to calculate uncertainty of a feature which user of the CMM wish to know. We may have two possibilities namely: i) Feature based metrology [9] which directly traces propagation of error from observed value to target feature, and ii) Constrained Monte Carlo simulation which rolls plural dice constrained each other at once.

Rolling constrained plural dice for trial series

Typical uncertainty estimation utilizes Monte Carlo simulation that rolls a die several

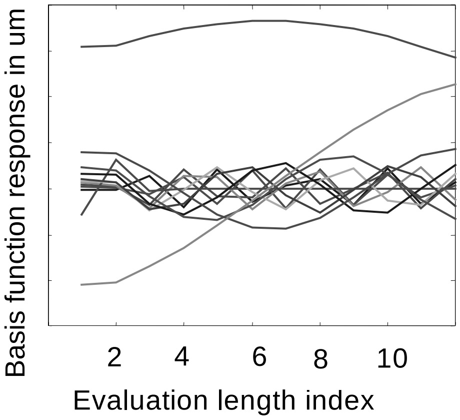


Fig. 3 Decomposed basis function

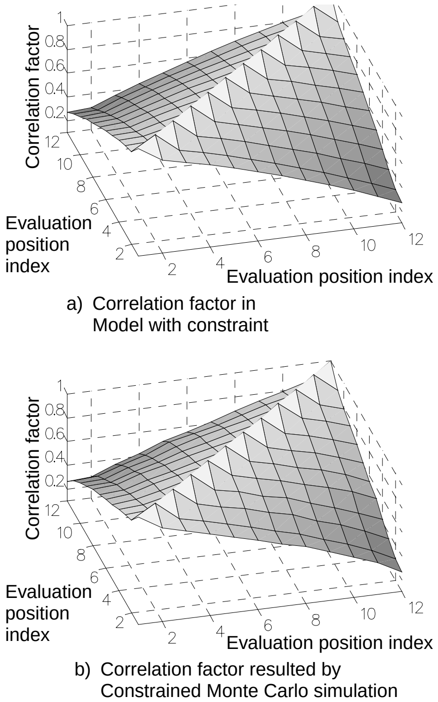


Fig. 4 A verification result of Constrained Monte Carlo simulation

times to give possible deviation value for all the necessary input parameters. This characteristic requires, on the other hand, the extra basis function to describe uncertainty contribution with constraint. Proposed model in this study fundamentally includes variance and also covariance as spatial constraint too. A new idea to roll plural dice with constraint characteristic is considered. Authors propose an algebraic solution for this problem. The proposed method is drawn in Fig.2 on its right bottom side as the constrained Monte Carlo simulation. It utilizes the eigenvalue decomposition of the task specific covariance matrix into a linear combination of spatial basis functions. An example of the decomposed basis function is shown in Fig. 3. This example simulates size measurement on a step gauge with 12 different length inline. The horizontal axis indicates observation position by the indexing number, and the vertical axis does geometric deviation derived by respective basis function. Qualitatively speaking, respective basis function represents spatial frequency with order of 0th, 1st, 2nd, and so on.

The recomposition process is performed by setting randomly fluctuated amplitude to respective basis function, and by combining them. A series of trial values satisfying the statistical process defined by the constrained covariance matrix can be generated by simply applying random generator on the basis function. A verification result of the constrained Monte Carlo simulation is presented in Fig. 4. The top figure a) shows an example of correlation factor distribution derived from ISO10360-2 template by the proposed model with constraint. Both horizontal axes indicate observation position by the indexing number identical to that of Fig.3. The vertical axis corresponds to correlation factor from 1,0 to attenuated value. Simulations were executed 1.000 times, and the task specific correlation factor was calculated from 1.000 population of trial series. The result was shown in the bottom figure b) of Fig. 4. Not only variance, but also correlation factor was well controlled by the constrained Monte Carlo simulation.

Spatial constraint on real CMM

The proposed model with constraint was applied on the real CMM on the production floor. The verification procedure conforms to that specified by ISO10360-2. Totally 350 CMMs were examined to extract statistical characteristic, especially spatial constraint observed on geometric deviation of real CMMs. The spatial constraint

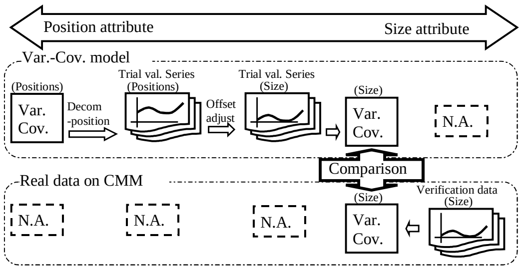
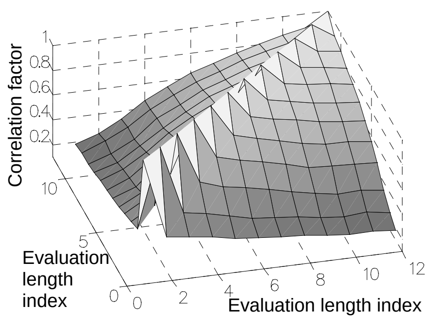
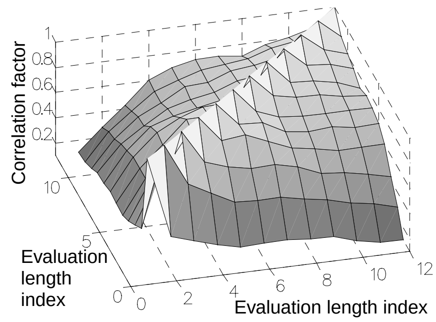


Fig. 5 Comparison procedure of spatial constraint



a) Correlation factor in Model with constraint, calculated on attribute of length



b) Correlation factor observed on 350 CMMs, calculated on attribute of length

Fig. 6 Correlation from model with constraint vs. real CMMs

extracted from real CMMs is compared to that predicted by the proposed model with constraint. The comparison procedure is schematically drawn in Fig. 5. Since the model with constraint stands on attribute of position, and experimentally observed verification results on real CMMs do on that of size, comparison is performed by statistical parameters with length attribute. A comparison result is shown in Fig. 6. Correlation factor predicted by the model with constraint con-forms to that observed on real CMM on the production floor.

Summary

A simple method of modelling task specific uncertainty on CMM is presented. Distribution profile of correlation factor predicted by the proposed model conforms to that observed on real CMM on the production floor. Application of this model on practical feature evaluation and comparison with the other uncertainty estimation procedure will be on consideration.

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