euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Dimensional correction of helically scanned cylinder data

Pei Liu[1, 2], Otto Jusko[1] and Rainer Tutsch[2]

[1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[2]Institut für Produktionsmesstechnik, Technische Universität Braunschweig, Schleinitzstraße 20, 38106 Braunschweig, Germany

pei.liu@ptb.de

Abstract
Form profiles of cylinders were acquired by optical helical scanning. Diameter data which were measured independently are used for dimensional correction of the 3D cylinder data. In this paper, a Gaussian Process (GP) fusion system is presented in fusion of form data and diameters. The fusion uses data from the core of helical scan, which is calculated by the GP based geometric fitting. The interpolation, which is based on the kernel-weighted average, is applied in the registration procedure. Afterwards, the corresponding points are linked by a GP linkage model. The spatial correlation of data is considered in fusion process. The effectiveness of fusion is tested by experiments. The fusion results are validated in compliance with the uncertainty of diameter. They are also compared to the results of fusing form profile obtained in the bird-cage strategy.

Keywords: Data fusion, Gaussian Process, form metrology, helical scan

1. Introduction

Helical scan of cylinder surface enables to measure precision form data in high point-density. In contrast to the bird-cage extraction strategy [1], the helix data holds a global coherence. However, a systematic measurement error, assumed to be a linear factor can be identified in result of helical scans. Such, the absolute coordinates of the data points are less precise than their relative coordinates. In this paper, a data fusion system is proposed to correct the dimensional error of helical scans with additionally acquired high precision diameter data. The GP fitting is employed to extract the core of helical scan. The points corresponding to diameters are interpolated by weighting the obtained core data in their neighbourhood. Finally, the interpolated data and diameters are linked by a GP linkage model.

2. Methodology

When cylinder surface is scanned, a deflection between the rotation axis of measuring machine and the z-guide can be detected, even though the cylinder is well tilted before measurement. This error needs to be corrected prior to the data fusion. Parameters representing the axis of cylinder can be evaluated by the least squares fitting of cylinder [2]. In this paper, the core of helical scan is calculated and used as the input for fusion. The fusion system works at the feature fusion level [3].

2.1. Extract core of helix data

The GP model is applied for geometric fitting of helix data and calculates the core of helix. It is assumed that an observation of helix data is composed of the designed geometry (helix), the spatial correlated systematic error E_s and the uncorrelated random error E_r [4]. For height vector $\boldsymbol{H} = [h_k, k = 1,\ldots, n]$, the observation is an univariable function $f(h_k)$ of height increment. The observation $r(h_k)$ modelled by GP is

$$r(h_k) = f(h_k) + E_s(h_k) + E_r(h_k) \qquad (1)$$

In GP model, the mean function and covariance function are the major focuses. The mean function is approximated by the first order polynomial and the squared exponential kernel is used for the covariance function. In this paper, all results are calculated by applying the GP toolbox [5] with minor modification. For each demanded position, a neighbourhood area containing several segments of helix profile is chosen for GP fitting. The dimension of area is determined by the width of kernel introduced in Section 2.2. The result of GP fitting is shown in Figure 1.

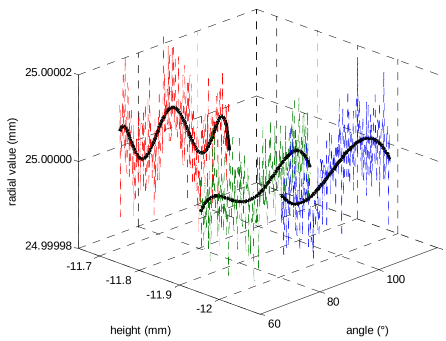

Figure 1. GP fitting of neighbourhood segments of helical scan: dashed lines are helix data; solid lines are the fitting results (core of helix)

It has been proved that GP is robust against local outliers. The precision in calculation of core should be guaranteed because it will further propagate to the fusion results. Hyper parameters in GP model are estimated by the maximum likelihood estimate (MLE). In such statistical training, using more data is likely to achieve more precise prediction. However, training large number of data is time consuming.

2.2. Interpolation

Registration is a procedure matching data points from different recourses. It finds corresponding points for fusion. Spatial data can be registered with respect to their coordinates. However, it is impossible for helix data, since each point is associated with its height, which means no distance of any point-pair corresponds to the diameter data. Therefore, interpolation or re-sampling is applied to the obtained core of helical scan to calculate values for the positions corresponding to diameters. The so-called Nadaraya-Watson kernel-weighted average is employed. We use the tri-cube kernel, which is a compact kernel with parameter λ controlling the width of kernel. Here, λ is used as a constant, which can also be an unknown variable estimated adaptively. In figure 2, results of interpolation are visualized.

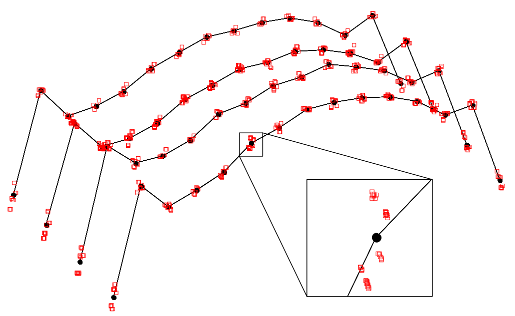

Figure 2. Results of interpolation: scatter crossings are the cores of helical scan in neighbourhood of demanded positions; solid circles are the interpolation results

2.3. Link helix data to diameter

A simple way linking two sets of data is to find their best-fit, for instance this problem can be solved by a least squares regression. However, the discrepancies between corresponding points are assumed independent and Gaussian distributed, neglecting spatial correlations. In order to take the spatial correlations into account, a GP linkage model is adopted. A calibrated diameter can therefore be expressed as

$$D_m = \left(r_c(h_k) + r_c(h_{k*})\right) + 2a + 2t \cdot h + E_s(h_k) + E_r(h_k) \quad (2)$$

where, $r_c(h_k)$ is the core at position h_k; a and t are the radial and deflection adjustments; position h_{k*} forms π angle to h_k.

The solution is similar to that stated in Section 2.1. Thereby, the fusion results are calculated by the trained parameters.

3. Case study

Details of measurement setup and procedures have been introduced in [6]. The helical scan result of the surface of a pressure gauge piston was acquired with the form measuring machine Mahr MFU110WP. Diameters were measured with the length comparator in two-point length measurements.

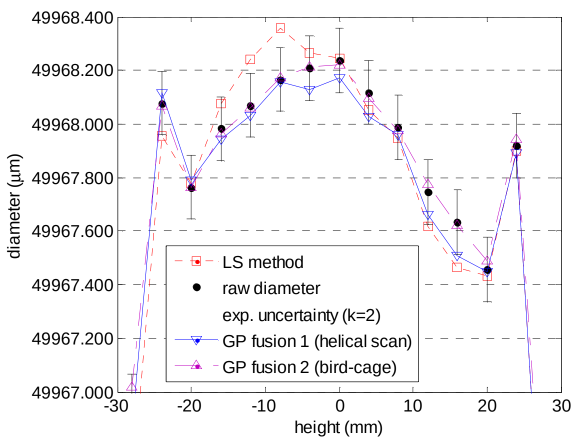

Figure 3. Comparison of fusion results

The nominal diameter is 50 mm and the height is 60 mm. The angular increment is 0.2° and the height increment is 0.2 mm. In sum, the helical profile contains 300 revolutions each with about 1800 points. For comparison, results acquired in bird-cage strategy with fifteen circles each with 3600 points and eight generatrices each with 3000 points are utilized. The results of comparison are shown in Figure 3.

4. Discussion

A major focus is to validate the proposed fusion system (GP fusion 1 in figure 3) with the raw diameter data taking its uncertainty of measurement into account. It shows that all fused values fall into the 95% confidence interval of the diameter measurements, which means the fusion results can be accepted.

Moreover, the GP fusion results using data acquired in the bird-cage strategy (GP fusion 2 in figure 3) has smaller bias than those using the helix data. This is because the profile segments (circles and generatrices) can be managed in a higher degree of freedom, while a global constraint has to be assumed to keep a consistency of helix data. From other point of view, fusion result acquired with helix data may be a better reflection of reality, since helical scan holds a consistency in each data point.

The LS method linking helix data to diameter is also applied. For linear LS solution, the result is unique. However, the fused data does not perfectly fit for diameters. It indicates that it is meaningful to adopt a correlated item to represent observations of measurement, as the GP model proposed in this paper. Actually, if such error is negligible, the results of GP fusion 1 will be quite close to those of LS method.

5. Conclusion

The fusion system based on the Gaussian Process was presented. It corrects the dimensional error of helical scan by fusing the core of helix with diameter data. The spatial correlation of data is taken into account in fusion process. The fusion results comply with the uncertainty of diameter which indicates the fusion is effective. To compare the results of fusing helix data and data acquired in the bird-cage strategy, further discussion should be implemented. More efforts need to be taken in evaluation of uncertainty for the fusion results.

6. Acknowledgements

The authors gratefully acknowledge support by the Braunschweig International Graduate School of Metrology B-IGSM.

References

[1] ISO 12180-2: 2011
[2] Forbes A B 1991 Least-squares best-fit geometric elements *NPL report*
[3] Dasarathy B V 1997 *Proc. IEEE.* **85** 24-38
[4] Xia H F, Ding Y and Wang J 2008 *IIE Trans.* **40** 931- 946
[5] Rasmussen C E and Nickisch H 2010 *J. Mach. Learn. Res.* **11** 3011-3015
[6] Jusko O, Neugebauer M, Reimann H, Sabuga W and Priruenrom T 2008 Dimensional calibration techniques for pressure balances to be used in the new determination of the Boltzmann constant *Proc. 1st Int. Cong. on Mechanical Metrology* (Rio de Janeiro, Brazil, 8-10 Oct. 2008) INFOSIM 14-23