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Configuration optimization of laser tracker stations for large-scale components in non-uniform temperature field using Monte-Carlo method

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Abstract

The laser trackers play an important role in fabrication and assembly of aircraft, spacecraft and other large-scale products, and optimization of laser tracker configuration station is one of the core issues. When laser trackers are used on the shop floor, environment factors, especially non-uniform temperature can induce considerable measurement uncertainty. Aiming to reduce measurement uncertainty of laser tracker, optimization of laser tracker configuration station for large-scale components in non-uniform temperature field using the Monte-Carlo method is proposed. Firstly, an improved mathematical model for measurement uncertainty of laser tracker is established. This mathematical model is more applicable to measurement uncertainty evaluation of laser tracker because it takes main measurement uncertainty sources (mechanism system and non-uniform temperature) into account. Secondly, the Monte-Carlo method is used to evaluate measurement uncertainties of laser tracker in different configuration stations. Based on the measurement mathematical model, a serial of simulation data can be generated to evaluate the uncertainty of measurement task. Through iterations, the optimal configuration station of laser tracker, in which measurement uncertainty is minimal, can be obtained. Finally, an example of measurement scenario about measuring the inspection jig of an aircraft door demonstrates that the proposed method is feasible and effective. The proposed approach to identify the optimal position of laser tracker is intuitionistic and efficient.

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Keywords: Laser tracker configuration; Large-scale product; Non-uniform temperature; Monte-Carlo method; Measurement uncertainty

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Nomenclature

LT	Laser Tracker
IFM	Interferometer
ADM	Absolute Distance Measurement
MC	Monte Carlo
ILVMS	Integrated Large Volume Measurement System
CAA	Component Application Architecture
OTP	Optical Tool Point
PSO	Particle Swarm Optimization

1. Introduction

The LTs play an important role in the fabrication and assembly of aircraft, spacecraft and other large-scale products due to their high speed, high accuracy and wide measurement range. Configuration optimization of LT stations is becoming one of the core issues [1,2]. The configuration optimization of LT station is to determine the best location of LT in the feasible region from the point of view of precision and reliability, taking the measuring error and uncertainty as optimization indexes, under the constraints of the shop floor

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physical environment, including temperature, lighting, flutter, humidity, pressure, etc.

When LTs are used on the shop floor, environment factors, especially non-uniform temperature can induce considerable measurement uncertainty. Temperature effects are often the dominant source of measurement uncertainty of laser tracker due to refractive index changes will influence measurement precision of IFM and ADM of LTs[3]. Because different configuration station of LT leads to different measurement uncertainty. The key issue of LT optimization configuration is to find the configuration stations of LT which can reduce measurement uncertainty of measuring characteristics or measuring points. At present, there are quite a few researches on the optimization of LT configuration in large-scale measurement. Tang et al. analyzed the site measuring uncertainty of the LT by moving instrument locations. Series experiments of single point and length were designed to obtain the site measurement uncertainty of LT [4]. Ouyang et el. paid a great attention to study how the time and temperature affect the measuring accuracy of LT. Their studies have shown that angular errors are the key contributors to measuring errors of LT. A device to measure angular errors of LT on CMM has been invented. Using this technique to calibrate the LT on the CMM the maximum measuring error of the LT in measuring distance of 1.56m has decreased [5]. Li et al. applied the Monte-Carlo method to evaluate the task specific measurement uncertainty of LT. The results of the MC method and LT measurements are in well agreement with each other [6]. However, these studies haven't established the measurement uncertainty mathematical model of LT in non-uniform temperature field and have not given an effective method to find the optimal configuration station of LT. Moreover, although manufactures of LTs provide the method to compensate temperature induced measurement uncertainty by using environment station, the temperature distribution is regarded as uniform field. The compensations are just based on wavelength variation from 20℃ to read of environment station, non-uniform temperature distribution in workspace, including temperature variation in space and time, was not taken into account.

Therefore, it is necessary to explore methods for seeking out LT optimal configuration stations in the non-uniform temperature field. Considering actual conditions of typical large-scale measurement and temperature field constraints, an optimization mathematic model of LT configuration station is constructed in this paper. An example of measurement scenario about measuring the inspection fixture of an aircraft door shows that the proposed method is effective and promising.

2. Mathematical model for LT measurement uncertainty

2.1. Measurement uncertainty analysis

LT is a portable spherical coordinate large-scale measurement system. The LT is basically a spherical coordinate measuring machine. It measures 3D coordinates with laser beam by following a mirrored spherical probe. The control unit combines the distance information from laser interferometer and the angle information from encoders to calculate 3D coordinates of the reference target. The measurement uncertainty is produced from the LT system, together with the environmental and operational factors, as can be seen in Fig.1.

In different measurement tasks, these factors may make different contributions to measurement uncertainty. However, LT system errors and non-uniform temperature field (including uniform in space and time) are always the dominant factors to induce the measurement uncertainty when a LT is used on the shop-floor.

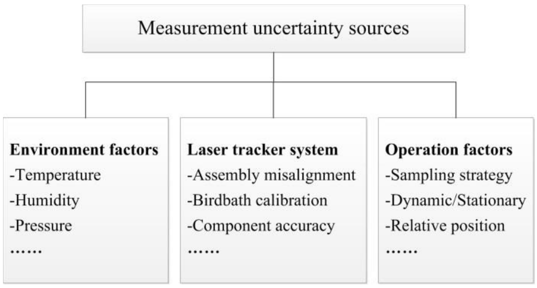

Fig. 1 Measurement uncertainty sources

2.2. System measurement uncertainty

LT can measure the distance (l) to the target point (P), the horizontal angle (α) and the zenith angle (β)， as shown in Fig.2. Measurement values of l, α and β are l_m, α_m and β_m.

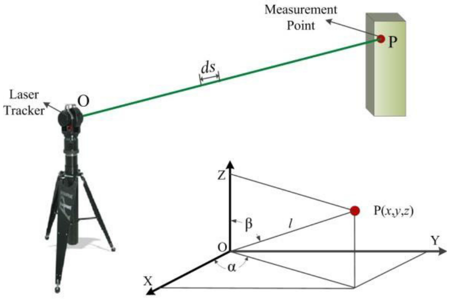

Fig. 2 Measurement principle of LT

The distance is measured by the laser interferometer components, and the angles components are measured by high-precision angle encoders. The coordinate of P can be determined as following

$$\begin{bmatrix} x_m \\ y_m \\ z_m \end{bmatrix} = \begin{bmatrix} l_m \cos\alpha_m \sin\beta_m \\ l_m \sin\alpha_m \sin\beta_m \\ l_m \cos\beta_m \end{bmatrix} \tag{1}$$

where, l_m, α_m and β_m are measurement values, x_m, y_m and z_m are measurement coordinate values of P. System measurement uncertainty of LT, which is induced by assembly misalignment, components accuracy and other factors of LT, will cause the difference between measurement values and actual values. The measurement uncertainties of α, β and l can be expressed by