

CMM Inspection Combining Tactile Probing and Laser Scanning

H. Zhao, N. Van Gestel, P. Bleys, J. P. Kruth

Abstract:

Combining contact and non-contact CMM probes provides a promising solution to meet the increasing requirements on complexity and accuracy of dimensional metrology, and benefit inspection performance. However, the automated planning of measurement strategies for such hybrid CMM systems hasn't been well addressed yet. This paper proposes an automated inspection planning approach for CMM inspection combining tactile probing and laser scanning. The right sensor is first selected for each feature being inspected. According to the selected sensor, the suitable procedures are performed to create the inspect plan automatically. Experiments are carried out to verify the developed approach.

Keywords: CMM; laser scanning; tactile probe; inspection planning; multiple sensors

1. Introduction

Due to their flexibility and accuracy, Coordinate Measuring Machines (CMMs) have been widely adopted as general-purpose tools for geometric inspection in dimensional metrology [1, 2]. CMM inspection with multiple sensors is being applied to meet the increasing requirements on complexity and accuracy of dimensional metrology [3]. Generally, touch trigger sensors and laser line scanners have the complementary characteristics in probing speed, coverage, accuracy, etc [4]. Combining the two can thus improve the inspection performances because the metrological evaluation can benefit from both sensors.

Generally, the performance of a CMM-based measurement system, such as measuring time, measurement uncertainty, error, etc., highly depends on the applied inspection planning strategy [5]. An optimal planned inspection process contributes greatly to achieving both time and accuracy objectives. However, planning of measurement strategies that combine tactile probing and laser scanning on a CMM is not well addressed [6] and usually done in interactive way, which can be very time-consuming and far from optimal.

This paper proposes an intelligent 3D CAD-based inspection planning tool which can plan the measurement strategy automatically for GD&T verification and quality control. The process flow is described in fig. 1. The planning tool first extracts inspection features, being geometries associated with PMI (Product and Manufacturing Information) items and selects the most suitable sensor for each inspection feature. Afterwards, the inspection plan for each

inspection feature is generated according to the selected sensor. The planning results are verified with actual CMM measurement.

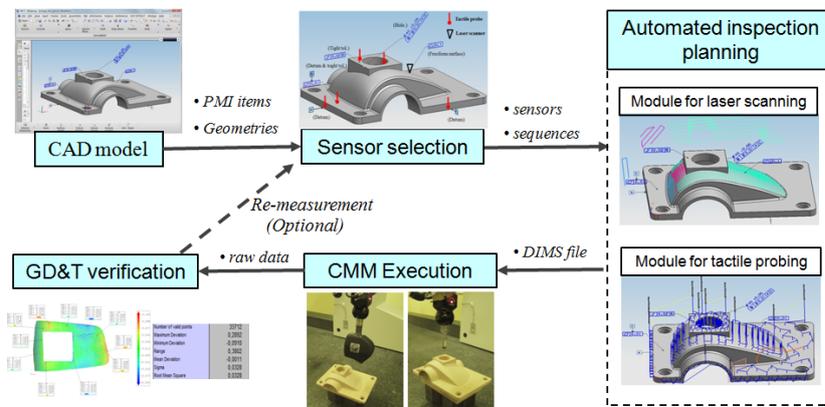


Fig.1: Process flow of the Inspection system

2. Sensor selection

When multiple sensors are employed, a feature may be measured by a single sensor (a tactile probe or a laser scanner) or by both types of sensors to reduce the measurement uncertainty or obtain more details in some special regions. Choosing the right sensors for each inspection feature is the first critical issue to reach an optimal inspection planning.

Many factors influence the sensor selection. They should be taken under consideration to establish the selection criteria. The developed method for sensor selection depends on the following knowledge:

- (1). Tolerances of/on features. The selected sensor should ensure a sufficient uncertainty on the measured results. The most common used ratio of sensor uncertainty to the tolerance being inspected are 1:5 and 1:10.
- (2). Geometric properties, like geometry type (e.g. hole, shaft, etc.), shape type (cylinder, plane, etc.), topology, etc. The accessibility of a sensor to the feature depends greatly on these properties. The selected sensor type(s) should be convenient and be able to access the full feature.
- (3). Dimensions of features. The dimensions or sizes of features should be considered to achieve an optimal compromise between time spending and accuracy.
- (4). PMI items associated with surface properties: material, surface finish, color, etc. These factors also influence the performance of the sensors, and should be considered for sensor selection.

As the final step, the inspection features are classified into two different groups according to their selected sensors. The measurement strategy for each group is planned automatically based on the respective methods discussed in the next section.

3. Automated inspection planning

Several setups of the part being inspected are usually necessary in order to perform a full inspection. The setups of the part are thereby first determined and the inspection features are organized accordingly. Then, two modules are developed to plan the measurement strategies for laser scanning and tactile probing respectively.

3.1. Module for laser scanning

The module plans the laser scan strategy by fixing the following two basic issues: view angle computation and scan path generation.

(1) View angle computation.

Given a scan feature, the required view angles should be computed to ensure that the feature can be fully scanned. For this purpose, the feature is discretized to a dense set of points (\mathcal{R}), from which the required view angles are determined by the following procedures:

Initialization: The uncovered region (\mathcal{R}_u) is set as \mathcal{R}

$$\mathcal{R}_u = \mathcal{R} \quad (1)$$

View angle seed creation: The new view angle seed (\vec{v}_s) is created as the normal of an arbitrary point (p_j) in \mathcal{R}_u :

$$\vec{v}_s = \overline{n(p_j)} \quad (2)$$

Where, $\overline{n(p_j)}$ is the normal vector of the point p_j .

Covering region calculation: The covering region ($\mathcal{R}_c(\vec{v}_s)$) to \vec{v}_s is calculated as:

$$\mathcal{R}_c(\vec{v}_s) = \{p | \theta(\vec{v}_s, \overline{n(p)}) < \theta_r, p \in \mathcal{R}_u\} \quad (3)$$

Where, $\theta(\vec{v}_1, \vec{v}_2)$ is the angle between vector \vec{v}_1 and vector \vec{v}_2 . θ_r is the maximum reflective angle of the applied laser scanner.

Afterward, the occlusion points which are inaccessible by laser scanner in any view angle are removed from $\mathcal{R}_c(\vec{v}_s)$, and a new view angle (\vec{v}_N) is calculated as the mean normal of the points in $\mathcal{R}_c(\vec{v}_s)$:

$$\vec{v}_N = \frac{\sum_{p \in \mathcal{R}_c(\vec{v}_s)} \overline{n(p)}}{\sum_{p \in \mathcal{R}_c(\vec{v}_s)} \|\overline{n(p)}\|} \quad (4)$$

The covering region ($\mathcal{R}_c(\vec{v}_N)$) related to \vec{v}_N is then calculated using formula (3).

Updating: The sizes of the covering regions $\mathcal{R}_c(\vec{v}_s)$ and $\mathcal{R}_c(\vec{v}_N)$ are compared. If $\mathcal{R}_c(\vec{v}_s) < \mathcal{R}_c(\vec{v}_N)$, \vec{v}_s is updated as \vec{v}_N and the process goes to step (c). Otherwise, the process goes to step (e).

\vec{v}_s is saved as a required view angle and the uncovered region is updated:

$$\mathcal{R}_u = \mathcal{R} - \mathcal{R}_c(\vec{v}_s) \quad (5)$$

Termination: The computing repeats the steps from (b) to (e) until the termination condition is satisfied as $\mathcal{R}_u = \emptyset$.

(2) Scan path generating

The scan path is generated based on the associated covering region ($\mathcal{R}_c(\vec{v}_s)$) to each required view angle (\vec{v}_s). The scan path comprises of the scan lines for data acquisition and the connecting lines to connect scan lines for continuous scanning. The moving directions of the scan lines are determined based on the surface curvature information of $\mathcal{R}_c(\vec{v}_s)$. The scan lines lay on the position elevations of the laser scanner (fig. 2), which are determined based on the FOV (Field of View) information of the laser scanner. The points in $\mathcal{R}_c(\vec{v}_s)$ are then projected to their corresponding elevations. The number of scan lines on each elevation and the length of each scan line can be determined based on the information of the convex hull of the projected points on that elevation.

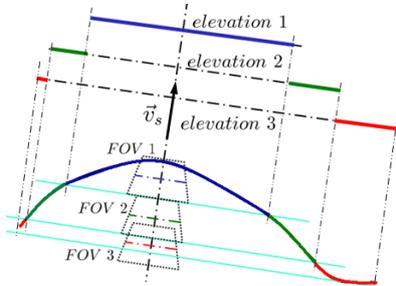


Fig. 2: position elevations of the laser scanner

3.2. Module for tactile probing

The module focuses on touch trigger probing measurement. It first the probing points based on the tolerance and the measurement uncertainty simulation [7]. The basic philosophy of the developed method for inspection path generation is using the profile of the obstacle as guidance for collision avoidance, as illustrated in fig. 3.

The general procedures can be described as follows. If collision happens in between two points being connected during collision checking, the shortest profile of the obstacle on the probe tip moving plane is extracted. The profile is then approximated as a set of linear segments and the collision-free path is generated by offsetting the segments' set with a safe distance.

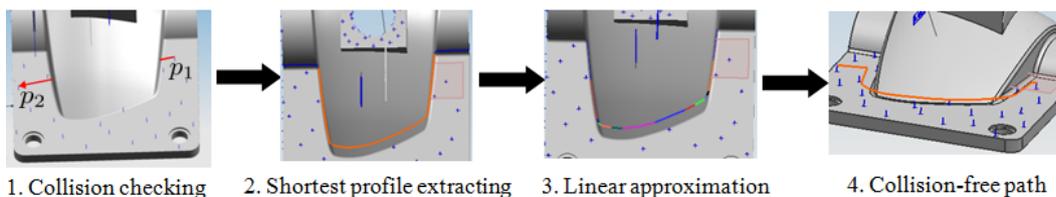


Fig. 3: Procedures for collision-free inspection path generation

4. Case study

The proposed methods are verified by a case study. In this case, the software decides to measure the flat horizontal surface by tactile probe while the freeform surface is measured by laser scanner automatically according to the design specifications.

The tactile inspection path with 37 points for the flat horizontal surface is given in the left figure in fig. 4. The actual measured points followed the planned path is shown in the right figure in fig. 4. The actual flatness is 0.1905mm. The laser scanning plan created by the proposed methods for the freeform surface is given in the left figure of fig. 5. The right figure in fig. 5 shows the initial acquired point cloud. With respect to the CAD freeform surface, the standard deviation (σ), the maximum (δ_{max}) and minimum (δ_{min}) deviations of the point cloud is calculated and listed in fig. 5. The experiments demonstrate that the proposed methods provide efficient inspection planning for both laser scanning and tactile probing.

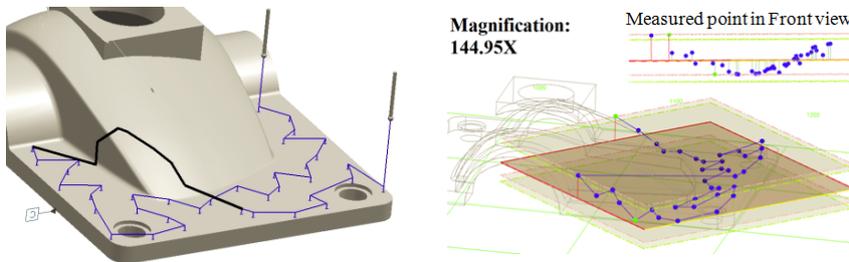


Fig. 4: Tactile measurement. The left figure is the tactile planning result, the black path is a collision-free path; the right one is the actual inspection path

5. Conclusion

An intelligent and automated inspection planning tool is proposed for CMM inspection combining tactile probing and laser scanning. The planning tool extracts inspection features from a given CAD model and selects the suitable sensor for each feature according to its design specifications. Two modules are developed to create the inspection plans for laser scanning and tactile probing. They can be chosen according to the selected sensor to generate the inspection plans automatically.

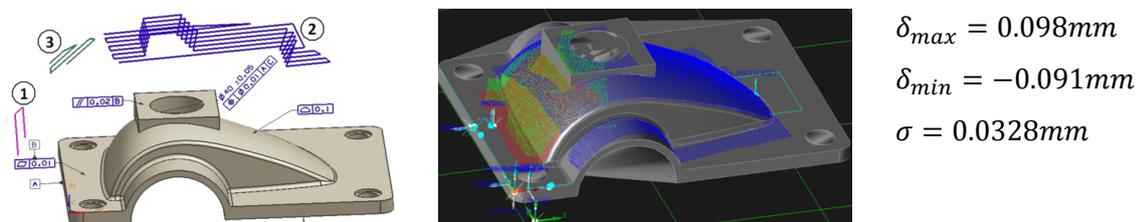


Fig. 5: Laser scanning measurement of the freeform surface. The left figure is the planning result; the right one is the initial acquired point data.

Reference

- [1] R. Schmitt, H. Zheng, S. Nisch; Approach for the flexible integration of CMMs into the production line, *Proceedings of LAMDAMAP*, 2009, pp: 433-441
- [2] T. Shen, J. Huang, C. Meng; Multiple-sensor planning and information integration for automatic coordinate metrology, *Journal of Computing and Information Science in Engineering*, 1 (2001), pp 167-179
- [3] A. Weckenmann, X. Jiang, et al.; Multisensor data fusion in dimensional metrology, *CIRP Annals – Manufacturing Technology*, 2009, pp 701-721
- [4] Y. Huang, X. Qian; A dynamic sensing-and-modeling approach for three-dimensional point-and-area-sensor integration, *Journal of Manufacturing Science and Engineering*, 129 (2007), pp 623-635
- [5] M. Cho, H. Lee, G. Yoon, et al., A feature-based inspection planning system for coordinate measuring machines, *Journal of Adv. Manuf. Technol.* 2005. 26: pp 1078-1087
- [6] A. Mohib, A. Azab, H. ElMaraghy, Feature-based hybrid inspection planning: A mathematical programming approach, *Journal of Computer Integrated Manufacturing*, 2009, 22(1): pp 13-29
- [7] J.P. Kruth, N. Van Gestel, P. Bleys, et al., Uncertainty determination for CMMs by Monte Carlo simulation integrating feature form deviations. *CIRP Annals – Manufacturing Technology*, 2009, 58: pp 463-466