New Approaches to the Improvement in Efficiency of Dimensional Measurements on Multi-Sensor Coordinate Measuring Machines

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Abstract. *Efficient dimensional measurements on multi-sensor coordinate measuring machines require optimised inspection plans. From the industrial management point of view the optimisation of the inspection plan is aimed at the minimisation of total measurement costs. That is connected with the minimisation of measurement times based on the optimisation of measurement ways and points in consideration of the tolerance-uncertainty-ratio. Therefore, the selection of an adequate sensor, capable of measuring the inspection feature within its specification, is of extreme importance.*
Within this paper different approaches to efficient multi-sensor coordinate measurements based on optimised inspection plans are presented.

Keywords: Uncertainty, Monte-Carlo-Method, Coordinate Measurements, Cost of Measurement, Sensor Travel Time

1. Introduction

For the measurement of geometrical features coordinate measuring machines (CMMs) with different tactile and visual sensors are widely used and important due to their large scope of application and their flexibility in the measurement of different workpieces. Within the inspection planning all parameters for the measurement are defined e. g. the selection and characterisation of sensors and the measurement strategies. The selection of an adequate sensor results from multifarious points of view e. g. geometrical properties and surface characteristics of the unit under test and tolerance limits. Also the measurement uncertainty or subsequent disputed user risks and costs resulting from this are decisive for the inspection planning. The improvement in efficiency of measurements on CMMs could result on the one hand from the increasing automation of perspective processes, for example the essential estimation of the measurement uncertainty, and on the other hand from optimisation of measurement procedures.

2. Model for efficient dimensional measurements

Increasing the benefit of a company always goes ahead with lowering costs. In case of measuring parts with multi-sensor CMMs [1] costs of a measurement can be calculated with

$$K_M = t_M \times (k_P + k_{KMG})$$

with K_M is the costs of the measurement, t_M is the time for the measurement, k_P is the cost rate for employees and k_{KMG} the cost rate for the machine. The time for the measurement results from

$$t_M = t_{Ein} + t_K + t_{KS} + t_A + n \times \left(\sum_{j=1}^{k} \sum_{i=1}^{m} t_{ij} + \frac{s_{Verf}}{v_{Verf}} + t_{TW} + t_U \right)$$

where is t_{Ein} the warm up time of the machine, t_K the time for the calibration of the machine,

t_{KS} the time for creating the coordinate system and t_A the time for mounting the test piece. To this the sum of t_{ij}, the time for measuring objects $i=1,...,m$ with the sensor $j=1,...,k$, plus the time for positioning, represented by the distance between measuring objects s_{Verf} divided by the speed for the positioning v_{Verf}, added by t_{TW}, which is the time for changing the sensor, and t_U, the time for changing the test piece, if more than one is measured. This sum is multiplied by n, which is the number of pieces.

To minimize the time of the measurement the time for detection of a measurement feature and the travel time of the sensor between the features has to be optimized. While travel time is connected with the order of the features the time for the detection highly influences the measurement uncertainty and with that also the proceeds caused by the measurement [1],[2].

3. Minimization of the travel time of the sensor

Calculating an exact solution for the best order of measurement features will cause run time problems if the number of features rises above 10. This is why heuristic methods can be used. To simulate the intuitive behavior of the operator the model of Nearest Neighbor is used as reference in this paper. The model starts with a starting point and integrates the closest point into the route (Fig. 1 a). Especially at the end of the route this model delivers wide ranges to travel.

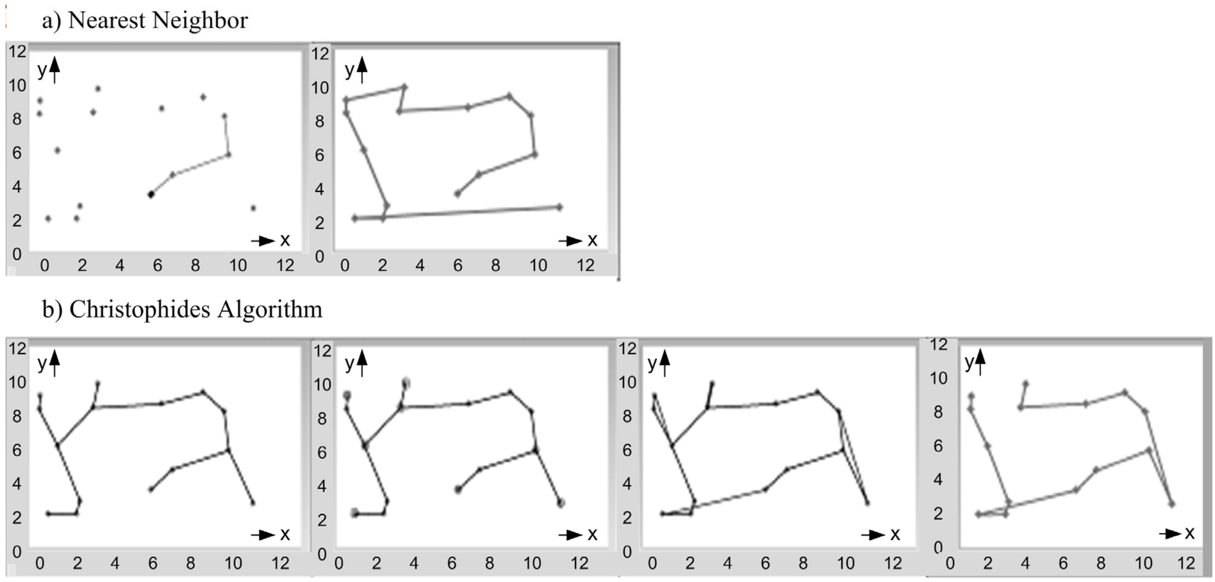

Fig. 1. Comparison of Nearest Neighbor method vs Christophides Algorithm.

A heuristic model to optimize travel distances is the *Christophides Algorithm* (Fig. 1 b). The algorithm works in four steps:

1. Creating a minimal spanning tree
2. Find a minimal perfect matching
3. Integrate points with odd number of neighbors
4. Create an Euler tour

As a result of this method the travel distance could be minimized about 14%.

4. New approach to the efficient GUM-conform uncertainty estimation

The proposed method lays the foundations for the automated indication of a complete measurement result consisting of the best estimate and the GUM-conform expanded measurement uncertainty [3] for coordinate measurements with visual sensors. The digital image of the unit under test is the prerequisite of measurements with visual sensors and represents all available information. Therefore, the newly developed method is based on knowledge about the quality of the image, which represents the measuring scene (Fig. 2 a). Significant image information in combination with measurement results of supplemental experiments in preliminary investigations, saved in the knowledge database (Fig. 2 c), is applied for the estimation of the measurement uncertainty. During the detection of a coordinate point actual quality parameters (Fig. 2 a) are determined and the model for uncertainty estimation is adequately adapted. Due to the non-linear fitting algorithms, characteristical for dimensional measurements, numerical methodologies especially the Monte-Carlo-Method [4] is used for uncertainty propagation.

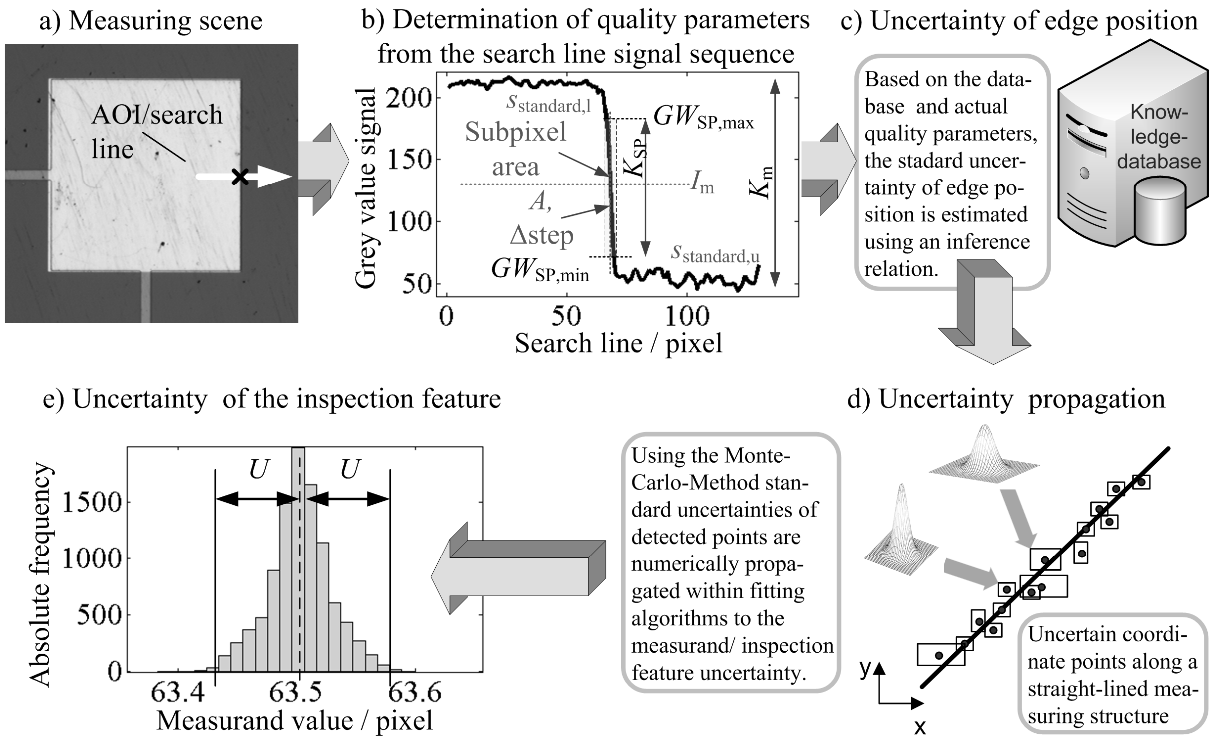

Fig. 2. Methodology for efficient uncertainty estimation of CMM-measurements using visual sensors [5], [6].

It could be shown, that the novel approach (Fig. 2) gives estimates of measurement uncertainty which are practicable and widely-agreed with experimental effectuated uncertainty declarations. The estimated measurement uncertainty by this means enables the user the evaluation of the reliability of the indicated measurand and the comparability of several measurements without the realisation of extensive supplemental experiments or calibrated workpieces, such as e. g. required in [7].

5. Conclusions

The proposed approaches lay the foundations for efficient measurements on multi-sensor CMMs. It could be shown, that the novel methods are essential prerequisites to bring forward the automation of perspective processes associated with the inspection planning. Thus, the measuring courses of action and the measuring results can be compared directly on different CMMs. All approaches, presented in this paper, have to be combined in one comprehensive system. Therefore, prospective research activities at the department of quality assurance at Ilmenau University of Technology will deal with knowledge-based simulation to create optimised inspection plans.

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