Quality Measures for Optical Probing in Optical Coordinate Metrology

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Abstract. *Typically measuring points in optical coordinate metrology are considered equally at the subsequent fitting of geometric elements, for example circle. This is due to the fact that no information regarding the related probing uncertainty of the individual measuring points is available.*

This paper outlines a novel approach for the determination of quality measures at the edge as a measure for the related probing uncertainty. The quality measures are based on the evaluation of the intensity characteristic at the edge, whose position is to be measured. The intensity characteristic is quantitatively evaluated on a scale of 0 to 100 equivalent to the range from excellent to very bad. Thereby five different criteria such as slope, width, form, noise and uniqueness of the edge are utilised. The overall quality measure is calculated as a weighted sum of the individual quality measures. The proposed quality measures have been applied at a number of different measuring objects. The experimental data prove the soundness of the new approach. The utilisation of the proposed quality measures results in a decrease of measuring uncertainty.

Keywords: quality measures, edge quality, probing uncertainty, optical coordinate metrology

1. Introduction

Dimensional measurements with optical coordinate measuring machines (CMM) are characterised by the measurement of contour points in the area of interest (AOI) in the image. The subsequent processing steps are most often the calculation of the parameters of geometric elements, for example circle, from the measuring points. Thereby different fitting methods are utilised, for example Gaussian least squares method or Chebyshev method such as minimum inscribed circle [1]. There exist also various approaches for outlier elimination [2], which are applied before the fitting calculation or as part of it.

The state-of-the-art is represented by the equal utilisation of all measuring points for subsequent processing steps. Based on the result of the internet, literature and patent search there is no method known for determining the probing uncertainty of individual measuring points in the field of optical coordinate metrology.

This paper proposes a novel method to calculate a set of quality measures in order to supplement each measuring point with quantitative information about its related probing uncertainty. Thereby the intensity of the pixels of search lines, which are representing the AOI, is analysed. The term search line refers to a set of pixels along a line that is roughly perpendicular to the edge in the image. Fundamental working principle of our method is the analysis of the intensity characteristic at the edge. It is expected that the novel method results in a decrease of the overall measuring uncertainty. The value range of the quality measures has been chosen in accordance to the I++ DME specification [3] which is specifying measuring commands for utilising dimensional measuring equipment (DME). The next section of this paper contains the detailed description of the calculation of the individual quality measures. After outlining the experimental data in section 3 the paper closes with a brief discussion of the attained results.

2. Calculation of the quality measures

The aim of the proposed quality measures is the evaluation of the intensity characteristic regarding its suitability for highly precise edge detection. Highly precise edge detection aims at achieving a minimum probing uncertainty of each measured point. The proposed quality measures are targeting the achievement of minimum stochastic measurement deviations. Systematic measurement deviations are not covered by this approach, for these are per definition determined and eliminated through suitable calibration and correction procedures.

Basically the overall quality measure for the edge quality Q_K may be composed of any set of individual quality measures. This paper proposes a set of five individual quality measures. They are slope, width, form, noise and uniqueness of the edge. The working principle of the different criteria is depicted in Fig. 1. The proposed set of quality measures contains no redundancies.

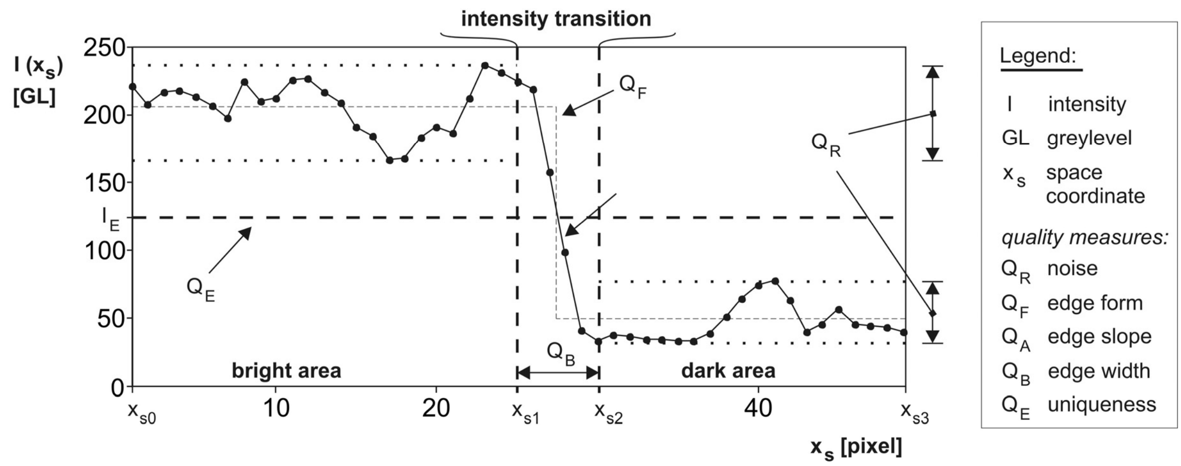

Fig. 1. Evaluation of the edge quality at a typical intensity curve along a search line captured in incident light.

The quality measure for noise Q_R aims at the evaluation of the noise of the intensity values. Thereby only intensity values on the right or on the left of the actual transition area are considered. A possible extension of this quality measure is to relate the noise to the contrast at the edge instead of relating it to the quantisation levels of the imaging sensor. Exemplarily a measure for the contrast at the edge is the difference between the smallest and the largest intensity value in the transition area. This extension enables a much sharper evaluation of the intensity characteristic. Moreover, it resembles a signal-to-noise ratio.

The slope of the edge is evaluated by the quality measure Q_A. Previous scientific investigations [5] have shown that the larger the slope the smaller is the probing uncertainty. The quality measure for the edge form Q_F delivers a measure for the deviation between the actual intensity curve and an ideal step function. The quality measure Q_B evaluates the width of the edge. In contrast to Q_A and Q_B, only Q_F enables the identification of distorted intensity curves. It compares the actual intensity curve with an ideal step function. Distorted intensity curves usually occur in incident light if the measuring object has a heavily structured surface, for example due to grinding processes. The quality measure Q_E serves the evaluation of the uniqueness. At measurements in incident light the reflection pattern from the surface of the measuring object is superposed with the diffraction effects at the edge of the measuring object. As result intensity curves may occur which are intersecting the mean intensity level I_E more than one time. The precise edge detection at such an intensity curve is extremely difficult.

In general it is to be expected that the overall quality measure for an edge of the same measuring object, captured one time in incident light and a second time in transmitted light, is significantly worse for incident light than for transmitted light. In optical coordinate metrology it is always preferred to measure in transmitted light respectively at the shadow image due to the smaller measuring uncertainty. The detailed formulas for all described quality measures are illustrated in Fig. 2.

Quality Measure (QM)	**Formula**
overall QM of the edge quality	$Q_K = \sum_{i=1}^{5} f_i \cdot Q_i$ $\quad \sum_{i=1}^{5} f_i = 1$ $\quad Q_i = [0..100]$
noise	$Q_R = 100 \cdot \frac{s_I}{Q_n}$ $\quad s_I = \frac{1}{2} \cdot s_{I,\,right} + \frac{1}{2} \cdot s_{I,\,left}$ $\quad n = \frac{x_{ps}}{\lvert x_{s1} - x_{s0} \rvert}$ $s_{I,Int} = \sqrt{\frac{1}{n-1} \sum_{x_{s0}}^{x_{s1}} \left[I(x_s) - \bar{I}_{Int} \right]^2}$ $\quad \bar{I}_{Int} = \frac{1}{n} \sum_{x_{s0}}^{x_{s1}} I(x_s)$
edge width	$Q_B = \begin{cases} 100: & \lvert b_{k,ideal} - b_k \rvert \geq 5 \\ 4 \cdot \left[b_k^2 - 2 \cdot b_{k,ideal} \cdot b_k + b_{k,ideal}^2 \right] \end{cases}$ $\quad b_k = \frac{\lvert x_{s2} - x_{s1} \rvert}{x_{ps}}$
edge slope	$Q_A = \begin{cases} 100: & I_A \leq 5 \frac{GL}{pixel} \\ 2500 \cdot \frac{1}{I_A^2} \end{cases}$ $\quad I_A = \left[\max \left(\frac{dI(x_s)}{dx_s} \right) \right]_{x_{s1}}^{x_{s2}}$
uniqueness	$Q_E = \begin{cases} 100: & t \geq 3 \\ 50: & t = 2 \\ 0: & t = 1 \end{cases}$ $\quad t \in Z$ and $t = 1, 2, \ldots$ $t = \sum_{x_{s0}}^{x_{s3}} \Gamma(I(x_s))$ $\quad \Gamma(I(x_s)) = \begin{cases} 0: & I(x_s) \neq I_E \\ 1: & I(x_s) = I_E \end{cases}$
edge form	$Q_F = 100 \cdot \lvert 1 - \psi_{max} \rvert$ $\quad \psi_{KM}(\Delta) = \int_{-\infty}^{+\infty} I(x_s) M(x_s - \Delta) dx_s$ $\psi_{max} = \left[\max \lvert \psi_{KM}(\Delta) \rvert \right]_{x_{s0}}^{x_{s3}}$ $\quad M = \delta(x_s)$

Legend :

x_s	search line coordinate	b_k	measured edge width
$I(x_s)$	intensity of the search line	$b_{k,ideal}$	ideal edge width
x_{ps}	distance of pixel centre points	I_A	measured maximum edge slope
n	number of pixels of the search line	t	number of edges
Q_n	number of quantisation levels of the image sensor	Γ	threshold function
s_I	standard deviation of the intensity values	I_E	mean intensity level at the edge
$s_{I,Int}$	s_I of the intensity values in the interval Int	ψ_{KM}	cross correlation of the edge signal and M
$\bar{I}_{Int}$	mean intensity in the interval Int	M	reference pattern
$\delta(x_s)$	Dirac impulse	Δ	shift between M and $I(x_s)$

Fig. 2. Concise overview depicting the formulas for each individual quality measure.

3. Experimental results

Images of different measuring objects have been captured and the edge quality Q_K has been determined (Table 1). Thereby measuring objects with typical characteristics of injection moulded plastics parts, microstructured parts, mechanically manufactured metal parts and planar structures have been considered. The individual quality measures are equally weighted for the calculation of Q_K.

Table 1. Measurement results for the edge quality determined at selected measuring objects.

Measuring object	Varied parameter	Q_R	Q_B	Q_A	Q_E	Q_F	Q_K
microfluidic chip for lab-on-a-chip systems	short search line	12.4	16.0	5.7	100.0	5.7	27.9
	long search line	12.7	16.0	5.7	100.0	9.4	28.8
microstructured plastics part for a spectrometer	focused image	2.5	64.0	0.5	0.0	2.0	13.8
	defocused image	1.5	100.0	3.7	0.0	7.1	22.5
milled metal object with surface structure s	s normal to search line	11.9	59.1	1.7	100.0	19.9	38.5
	s parallel to search line	2.5	55.0	5.7	0.0	2.9	13.2
circular planar structure, captured in:	incident light	14.4	0.0	0.5	50.0	3.9	13.8
	transmitted light	0.4	0.0	0.2	0.0	4.2	0.96

The application of the proposed quality measures leads especially at measurements in incident light to a significant reduction of the measuring uncertainty. This is due to the additional information regarding the probing uncertainty of each measuring point. When fitting the geometric element to the measuring points all measuring points with a bad edge quality Q_K are not considered.

4. Discussion of the attained results

The experimental data clearly show the soundness of the proposed quality measures. Evidently the length of the search line has no significant influence on the edge quality. The edge quality is significantly better in transmitted light than in incident light. Defocusing and surface structures perpendicular to the search line result in a deterioration of the edge quality. Thus, the attained experimental data fit with the expected behaviour that is known to experts in the field of optical coordinate metrology.

References

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