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METHOD FOR A ROBUST SEARCH LINE BASED ESTIMATION OF INTENSITY EDGE WIDTH IN BLURRED GRAY SCALE IMAGES FOR QUANTIFICATION OF MOTION- AND OUT-OF-FOCUS-BLUR

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ABSTRACT

This paper presents a robust method for the estimation of the edge width at contours in intensity gray level images to determine the grade of blur respectively motion and out-of-focus blur. There are several methods for estimating of intensity edge width, but a lot of them got as main problem a sensitivity to noise and for this reason large variances of the measuring results. The method bases on a histogram estimation of bright and dark level with respect to the noise followed by a scaling. Afterwards the scaled edge curve is fitted by Gaussian error function for a functional describing of the edge [1]. The fitted edge is following used for calculation of edge width described by Thomas principle used for lens quality estimations [2]. The functionality of the algorithm is evaluated with synthetically noised and realistic captures at different optical magnifications, exposure times and velocities of relative motion between camera and measuring scene.

Index Terms - image quality, edge quality estimation, image restoration basics, optical coordinate measuring

1. INTRODUCTION

Intensity edges in optical coordinate metrology are the base of the geometrical measures. The positions of the edges are determined by search lines based edge detection algorithms, e.g. dynamic threshold method for pixel accurate and photometric center method for sub pixel accurate edge position estimation [5]. Main requirements for the appliance of the detection algorithms are sharp and focused images with minimal blurring effects. Blurred edges are caused by diffraction effects of the optical system, defocusing and relative motion between camera and measuring object. The quality of the edges has to be sufficient for further processing steps, therefore it is necessary to quantify the amount of blur of the edge. There are different properties of the edge to estimate the quality, one of them is the edge width. Especially for motion blurred images the estimation by using the 1st derivative of the intensity signal to determine start and end of the edge is not applicable, because the superposed noise in the signal hinders or even eliminates the analysis. For repeatable results and low variances it is necessary to prevent the influence of the noise in the analysis of the edge signal.

2. STATE OF THE ART

In the field of optical geometrical metrology the properties of each intensity edges got influences to the measurement uncertainties of the resulting measures. Töpfer [4] uses a quality measure number QB from the range [0..100] to classify the quality of the edge regarding to the edge width. In our investigations we tried to use the quality measures to quantify the amount of motion- and out-of-focus blur, but the quality measure principle by Töpfer is not applicable for large blurred edges and sensitive to noise. Other approaches in the field of image processing estimate blur parameters by processing the whole image data using e.g. wavelet transformation, two-dimensional gradient, Soebel or Canny edge filter techniques, cf. [8], [9], [10]. These methods deliver results which are not applicable in further processing steps, because areas of interest (AOI) are only small regions of the whole image. This is especially the case by non planar measuring objects like drills or milling tools which have only small focused areas in the image. The gradient filter methods are sensitive to noise, especially for motion blurred edges, because the slope of the noise is much larger than the blurred edge slope. If edge widths are calculated from the whole image data, noise got impact to the results and errors occur. From these points of view the blur parameters have to be determined only by using the data of the AOI respectively of the search line data.

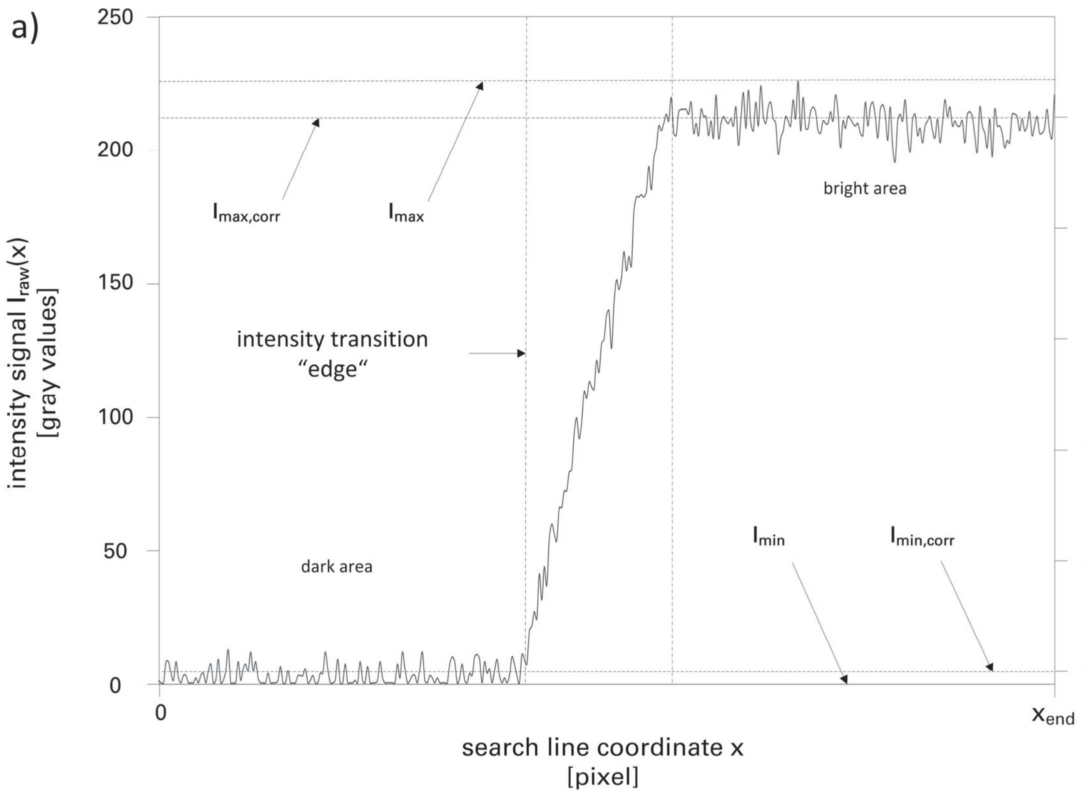
3. BASIC PRINCIPLES OF THE PROPOSED METHOD

The basics of the approach are a histogram based scale of the gray level raw data along a search line, a data fitting using the Gaussian error function and the estimation of edge width using an extended principle described by Thomas, cf. [2],[3].

3.1. Histogram based Scaling

For further processing using the raw data of the intensity along the search line, the data has to be scaled between the minimum and maximum level of the data. To avoid the influence of superposed noise in the data set, a histogram based analysis is used for estimating noise robust values of lower and upper gray levels. The histogram data only consists of the data of the search line, in comparison with an estimation using the histogram of the whole image, the frequency maxima of lower and upper gray levels are not disturbed by non interested regions of the whole image and in this case the maxima are easier to find. The whole image consists of the area of interest (AOI) and other for the processing non-interested areas, which are not used for the estimation of the edge width. Therefore the processed data should only consist of the data of the AOI to avoid the influence of the non interesting areas to the analysis. The upper and lower gray levels are determined in the following way:

a) build gray level frequency histogram of the search line gray level signal, figure 1a), depending on the range of data $I_{raw}(x)$, e.g. [0..255] for 8bit, cf. figure 1 b)
b) find the position of the first maximum of frequency $I_{\mathrm{min,max}}$ in the frequency histogram
c) find the second maximum of frequency $I_{\mathrm{max,max}}$ in the histogram, verify the second position with a dynamic estimated predefined minimum gap between upper and lower gray level, e.g. 20 percent of maximum contrast at the edge
d) correction of the found positions $I_{\mathrm{min,max}}, I_{\mathrm{max,max}}$ to avoid the influence of noise using a-priori knowledge, results are the corrected values of upper and lower gray value level at the edge transition: $I_{\mathrm{min},corr}, I_{\mathrm{max},corr}$, cf. figure 1a)



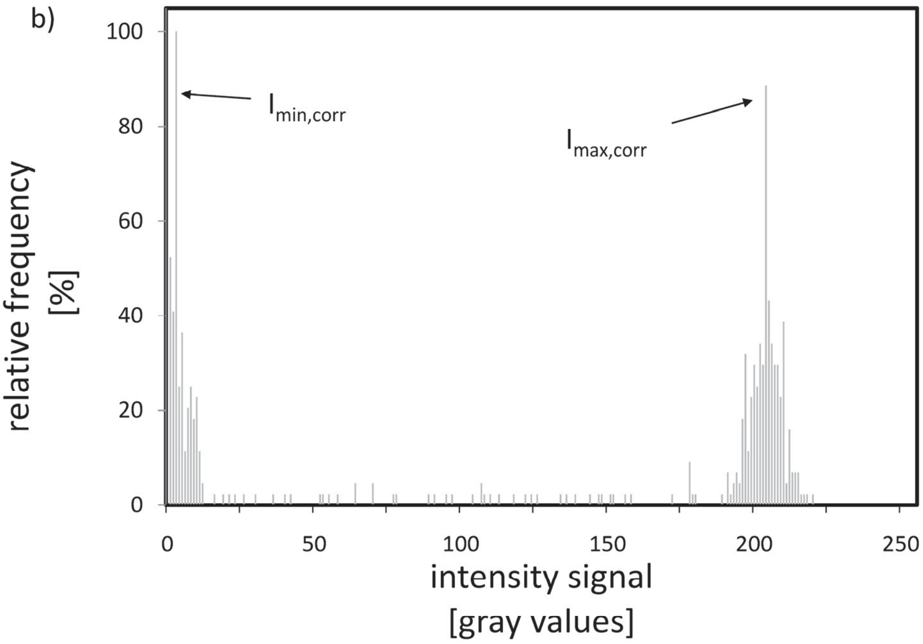


figure 1: a) intensity signal along a search line of a blurred image b) related intensity histogram of search line

After the determination of the upper and lower gray levels the scaling of the search line data is progressed and scaled in the following way:

$$I_{scaled}(x) = \left. \frac{I_{raw}(x) - I_{\min,corr}}{I_{\max,corr} - I_{\min,corr}} \right|_{x=0}^{x=x_{end}}$$

formula 1: scaling of gray values to range [0.0..1.0]

3.2. Fitting of Gaussian Error Function

Intensity edges can be described by different mathematical model approaches. In the literature the edge spread function (ESF) is described by the Gaussian error function erf, tangens hyperbolicus function tanh and several other ones, which are not further explained in this paper, detailed information about are described in [1]. The fitting and the analysis of the fits of different types of edge describing functions used for blurred edges provides the conclusion, that motion- and out-of-focus blurred edges are preferable fitted by Gaussian error function using a preceding scale [0.0 ..1.0] in double data range. Figure 2 depicts the scaled raw data and the for this case most suitable fitted Gaussian error function, the fitting is done by least square method.

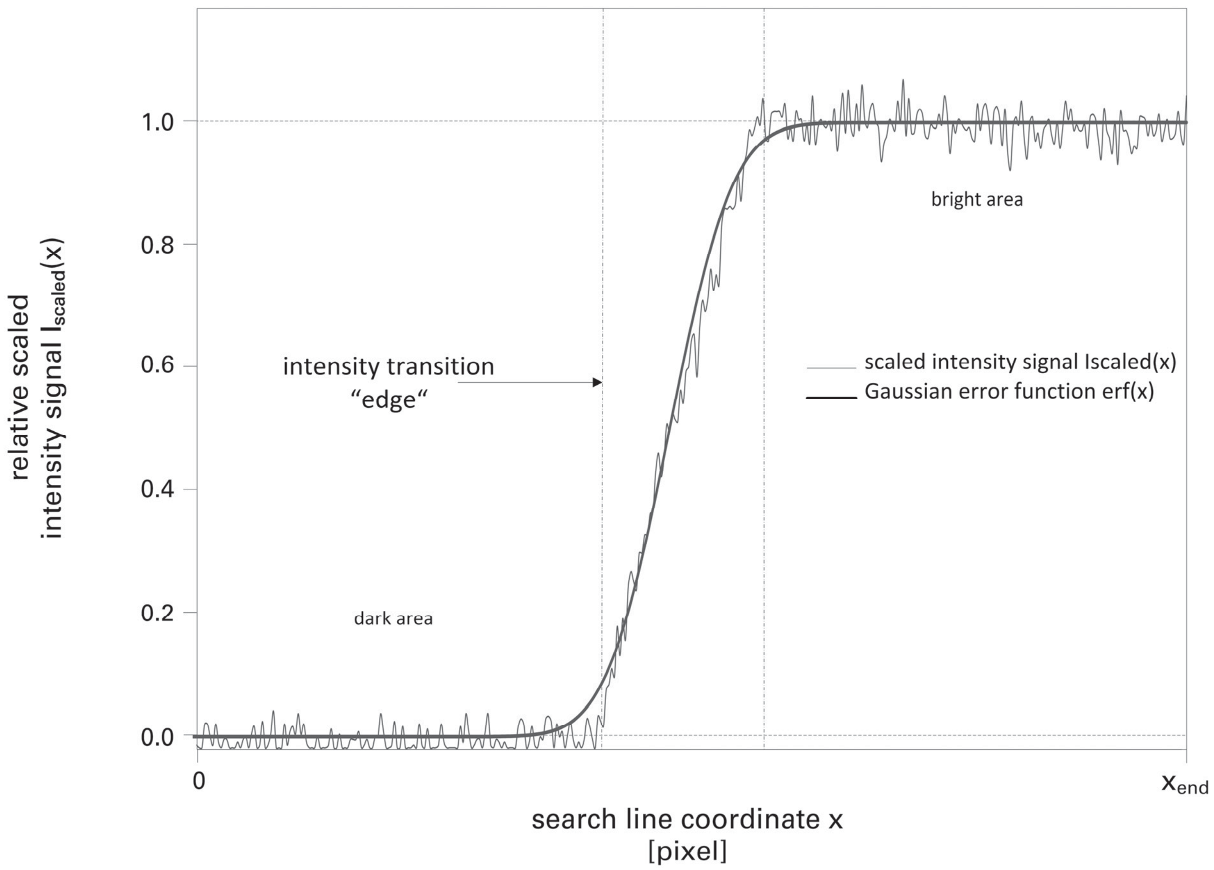


figure 2: fitted Gaussian error function on the edge transition signal

3.3. Edge width estimation using Thomas principle

The edge width estimation principle described by Thomas is based on the photometrical effects at the edge [2], [3]. The principle of Thomas was primarily invented for the estimation of the quality of imaging of lenses. In comparison to a theoretical edge, which is presented as an ideal step function, the realistic edge is extended by effects of diffraction and blur. The approach of Thomas uses the difference between ideal step function and realistic edge data to calculate two integral areas and to use them for edge width estimation, cf. formula 2 b). The approach takes advantages of the noise robust error function edge fit to divide the edge data into two parts initially and to find the sub pixel accurate edge position x_0 at 50 percent scaled gray level. Advantages of using the fitted function instead of the raw data are the robustness toward noise and only finite instead of infinite integral calculations caused of the convergence properties of Gaussian error function. The estimation of the edge widths is done by integration of the difference between fitted error function and Heaviside step function at two integration intervals for left and right edge width and a scaling with maximum intensity, in this case with the scaling maximum 1.0. Instead of Thomas result calculation [2], [3], another calculation procedure is used. The sum of both terms delivers preliminary result, which is multiplied with an empirical estimated factor of 3.8 to get the edge widths in pixel units. Figure 3 depicts the calculation of the integrals as described before.

$$I_{ideal}(x) = \theta(x) = \begin{cases} 0 : x < x_0 \\ 0{,}5 : x = x_0 \\ 1 : x > x_0 \end{cases} \quad Heaviside - Step - Function \qquad (a)$$

$$\Delta x_{left} = \frac{1}{I_0} \cdot \int_{-\infty}^{0} \left[I_{fitted}(x) - I_{ideal}(x) \right] dx \qquad (b)$$

$$\Delta x_{right} = \frac{1}{I_0} \cdot \int_{0}^{\infty} \left[I_{fitted}(x) - I_{ideal}(x) \right] dx \qquad (b)$$

formula 2:a) ideal Heaviside-step function a) estimation integral of left and right edge widths according to [2],[3]

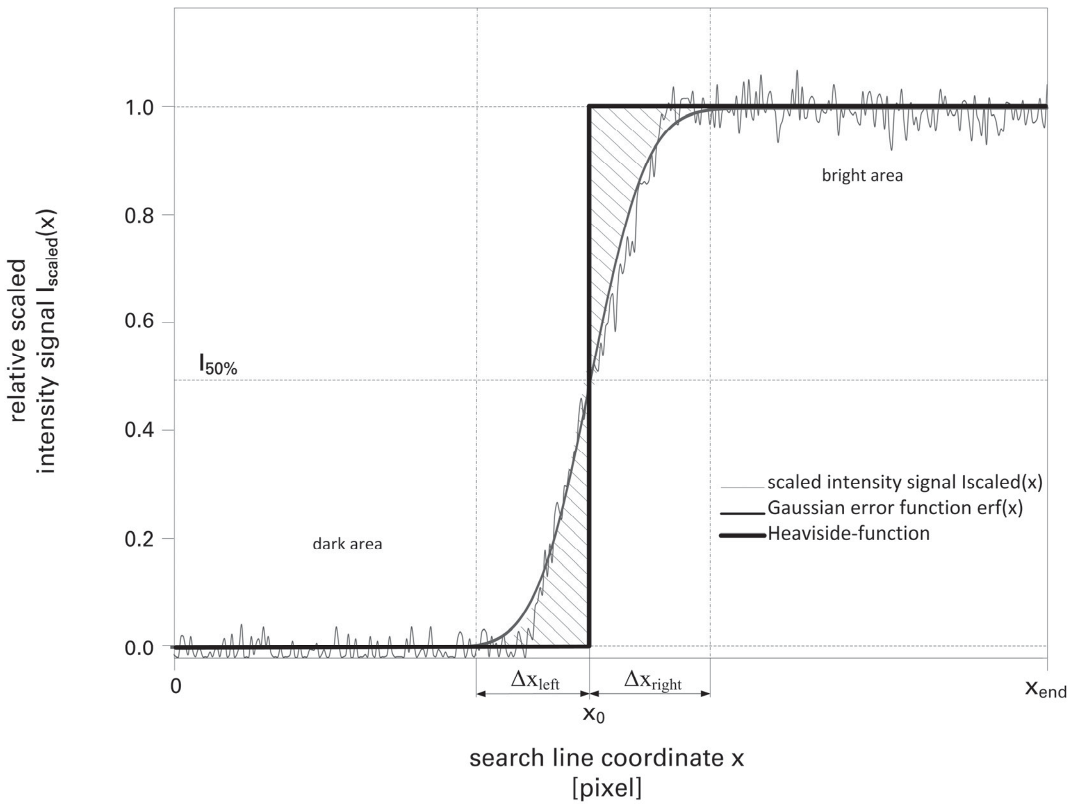


figure 3: estimation of edge widths according to Thomas[2], [3]

4. VALIDATION AND RESULTS OF THE APPLIANCE OF THE ALGORITHM

For validation of the functionality of the edge width estimation method, realistic blurred images are acquired with motion- and out of focus- blurred intensity edges using chromate calibration measuring objects and controlled parametrical test setups at coordinate measuring machine Mahr OKM GmbH UNI-VIS 250 with progressive scan CCD-camera, which deliver ideal optical images at different relative velocities, magnifications of the lenses and different exposure times of the camera. A proposed motion-blur model is validated [11] using the proposed edge width estimation method. Some results are depicted in figure 4.

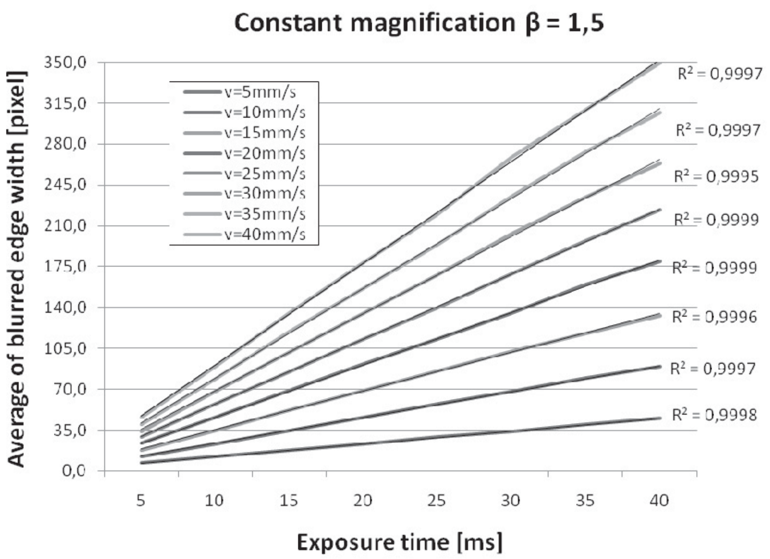


Figure 4:appliance of the method for motion blurred edge transitions at different exposure times and different relative velocities at constant magnification of the lenses

Instead of an estimation using a gradient method edge width calculation, the multi-linear model of motion blur at coordinate measuring machine was established by using the proposed method of this paper.

5. CONCLUSION

The proposed method of edge width estimation delivers adequate measuring results for the appliance on blurred intensity transitions. The appliance of the method is validated in detail on motion-blurred intensity transitions for the usage on motion-blurred image restoration, these further works are published simultaneous, cf. [11]. Further investigations will deal with the appliance of the proposed method to estimate AOI focus maxima to build new high precision focusing algorithms.

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REFERENCES

[1] E. Barney Smith, PSF estimation by gradient descent fit to the ESF, SPIE - Image quality and system performance III, 2006

[2] H. Thomas, Die Kante als Strukturelement zur Bildgütebewertung von Fotoobjektiven, Optik 66, 107, 1987

[3] H. Gross, Handbook of optical systems - Vol. 3, Wiley-VCH, 2006

[4] S.C.N. Töpfer, Quality measures for optical probing in optical coordinate metrology, Measurement Science Review Vol.7, Sec. 3, No. 4, 2007

[5] O. Kühn, Ein Beitrag zur hochauflösenden zweidimensionalen Geometriemessung mit CCD-Zeilensensoren (A contribute for high-resolution two-dimensional geometrical measuring using CCD line sensors), TU Ilmenau, Diss., 1997

[6] R.C. Gonzalez et al., Digital Image Processing 3rd edition, New Jersex: Pearson Education, 2008

[7] S. Holder et al., Edge quality based iterative deconvolution algorithm for motion blurred gray scale images for geometrical measures, 13th IMEKO TC1-TC7 Joint Symposium, Journal of physics - Conference series, 2010

[8] Zhang, F. et al., A New Approach to Estimate Image Blur Extent Based on Wavelet Module Maximum, International Conference on Intelligent Computing and Integrated Systems (ICISS), 2010

[9] Chung, Y-C., A Non-Parametric Blur Measure Based on Edge Analysis for Image Processing Applications, Conference on Cybernetics and Intelligent Systems, Singapore, IEEE, 2004

[10] Ferzly, R. et al., A No-Reference Objective Image Sharpness Metric Based on the Notion of Just Noticeable Blur (JNB), IEEE Transactions on Image Processing, Vol.18, No. 4, April 2009

[11] Xie, K., et al., An experimental of motion-blur in optical coordinate metrology for dynamic measurements of geometrical features, IMEKO Symposium TC7, Jena, August 2011