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AN EXPERIMENTAL STUDY OF MOTION BLUR IN OPTICAL CO-ORDINATE METROLOGY FOR DYNAMIC MEASUREMENTS OF GEOMETRICAL FEATURES

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Abstract − This paper presents an experimental study report of motion blur in a coordinate measuring machine (CMM) for dynamic measurements of geometrical features and validates a mathematic model. This model describes the relation between the CMM information about velocity, exposure time of camera, magnification of the lens, distance of adjacent pixels etc. and the grade of motion blur in the image. Three of these CMM input parameters are adjustable and were tested in experiments recording images for the analysis of motion blur. Also a new and robust method was used to estimate the grade of motion blur in the images statically. This new method is described in [2] in detail. It cooperates a fitting of an edge describing function and the knowledge of the photometrical effects at the intensity edge transition to calculate the blurred edge width (BEW) accurately and robustly. It has advantage to handle the significant blurred edge transition even with great superposed noise. The results of the experiments are figured in the diagrams. It has proved the validity of the proposed model, in short, the CMM parameters are proportional to the grade of the motion blur in the images. The work to validate this model is at first to determine the optimal operating point of CMM for dynamic measurement. Secondly it is very easy to determine the grade of motion blur directly from the model and further to generate a point spread function (PSF), which is used further for deconvolution. If there is blur as a fact of diffraction or defocus except for motion blur, the PSF of these blurs can be estimated by subtraction of the model result and the one of the new BEW calculation method in the form of a Gauss PSF. Thirdly with the CMM velocity information in the x- and y-axis, it can be easily and accurately determined the angle θ of the motion blur then it is easy to set a search line in θ in CMM to calculate BEW and it is possible to generate a 2D PSF.

Keywords motion blur, CMM, measurements of geometrical features

1. INTRODUCTION

Dynamic measurements of geometrical features in CMM can decrease the measuring time significantly and the motion blur (also out-of-focus blur for non-plane objects) is introduced. The popular techniques to diminish the motion blur are the application of strobe illumination and the reduction of exposure time. For example, Mitutoyo has developed a strobe illumination method using high brightness LEDs to realize non-stop vision measurement [3]. The LED-strobe is turned on for such a short time when the target area reaches the measurement point that the image does not blur. In the University of Technology Ilmenau a couple of works [1, 2] have addressed the problem of motion deblurring by deconvolution without strobe illumination or particular configuration of exposure time. According to the work in [4], until now there is no such research or product yet in the field of precision vision measurement, c.f. [4]. In [1] the features of motion deblurring for dynamic measurements of geometrical features in a CMM are summarized, one of them is that the PSF is linear in the x-y coordinate system. The feature simplifies the estimation of PSF. It is usually just necessary to calculate BEW in the image along the motion direction that causes motion blur. For this issue there are two difficult situations where it is not simple to perform deconvolution to restore the geometrical objects. One is except for motion blur caused by defocus or diffraction, which have no linear motion blur PSF but a Gauss PSF. The other is the linear motion located by an unknown angle. In order to handle these situations in this paper it is proposed to make use of the CMM information about velocity, exposure time, magnification and so on. A CMM is an electronic and optical system with high performance and its information is accurate enough to generate a proper PSF and then further to deconvolution. The work in this paper is regarded as an important part of motion deblurring using deconvolution in the field of precision measurement and there is no similar work to study the grade of motion blur in CMM [4].

The rest of this paper is organized as follows: In the second section, the model of motion blur in CMM is presented. The experiment and the results are given in third section. The fourth section is the discussion of the results. At last are the conclusion and the future work.

2. MODEL OF MOTION BLUR IN CMM

A CMM provides informations about velocity (V_x, V_y) in [mm/s], exposure time of camera t_I in

[ms], magnification of the lens β, distance of adjacent pixels (D_x, D_y) in [µm]. Except of (D_x, D_y) the other parameters are adjustable in CMM and determine the grade of motion blur in the image directly. The blurring grade $\vec{L}_{bm}$ [in pixel] is described as a part of the blurred edge width (BEW) and it indicates the displacement of every single point at the edge along the motion direction within the exposure time. Here is assumed that there is only a uniform linear motion blur without rotational motion. The model is described in Fig. 1. The parameters are proportional to the blurring grade $\vec{L}_{bm}$ in the image.

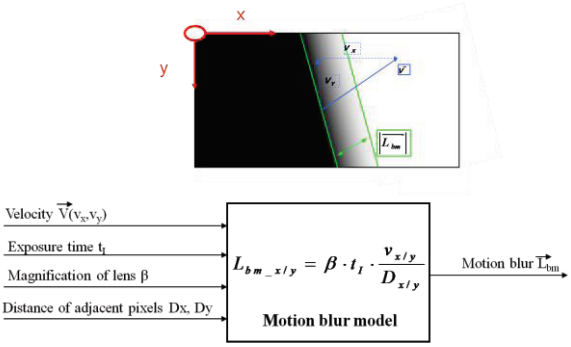

Fig. 1. Motion blur model in CMM

The blur caused by motion appears in increased intensity edge transitions. Additional blurs in the image can be also caused by defocusing and other effects from the optical system like diffractions, aberrations, telecentricity errors and others, which are summarized in the summand L_bOffset in Equation (1):

$$BEW_{meas} = \left|\vec{L}_{bm}\right| + L_{bOffset} \tag{1}$$

A new, robust search line based method is applied to measure BEW. It is presented in detail in paper [2]. This method cooperate the fitting technique and the photometrical effects in the edge transition to determine the BEW accurately and robustly even for the edge with great superposed noise.

3. EXPERIMENTS AND RESULTS

In order to measure as accurately as possible the impact of the CMM parameters on the grade of motion blur in the image, a chrome plate with standard patterns is chosen as measuring object, see Fig. 2.

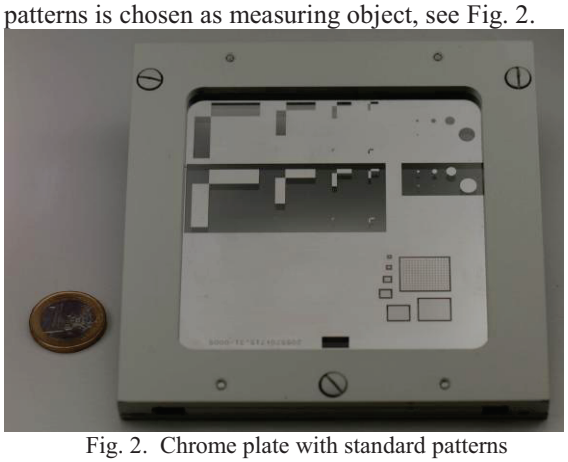

Fig. 2. Chrome plate with standard patterns

This measuring object is perfectly measured under transmitted or incident light and every pattern provides reproducible edge profile even in motion. Because it is a plate, defocus effects in motion can be ruled out. Defocus of the trial will be implemented separately in paper [2].

The experiments are conducted in the CMM UNIVIS 250 Mahr OKM GmbH and are divided into three groups according to the adjustable parameters above. In the first phase only the simple motion blur along x-axis was tested. Fig. 3 presents a sample of images at rest and in motion respectively. The inspected edge is perpendicular to the motion direction, i.e. x-axis. The optimal illumination and focusing adjustment should firstly be achieved and remain unchanged.

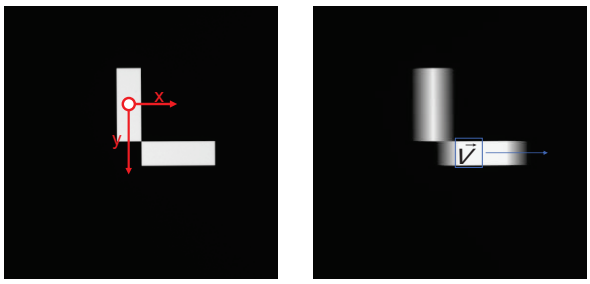

Fig. 3. Image at rest and in motion

Fig. 4-6 illustrates the results of the experiments, for a predefined adjustable, and then for the other two parameters.

Table I presents the values of the parameters under test. There are totally $8 \times 8 \times 5 = 320$ combinations from Table I regarding the three parameters and most of them are covered in the experiment plan.

TABLE I. Parameters under test

Parameter	Values
Velocity [mm/s]	5 **10** 15 20 25 30 35 40
Exposure time [ms]	5 10 15 **20** 25 30 35 40
Magnification	1 **1.5** 3 5 10

For every tested parameter-combination at least twenty good samples are reserved, in which there is at least one complete edge transition. In each sample five search lines along the motion direction are stochastically selected which contain the complete edge transition information to calculate the BEW. Repeating the calculation for other clips, totally one hundred search lines are achieved.

Our experiment plan has three parts regarding three CMM adjustable parameters. For a predefined parameter with a value that is often set in practice, the values for the other two parameters are selected according to TABLE I.

Fig. 4, 5 and 6 illustrate the results of the experiment in the following plan:

(1) Predefined velocity at 10mm/s.

(2) Predefined exposure time of camera at 20ms.

(3) Predefined magnification at 1.5.

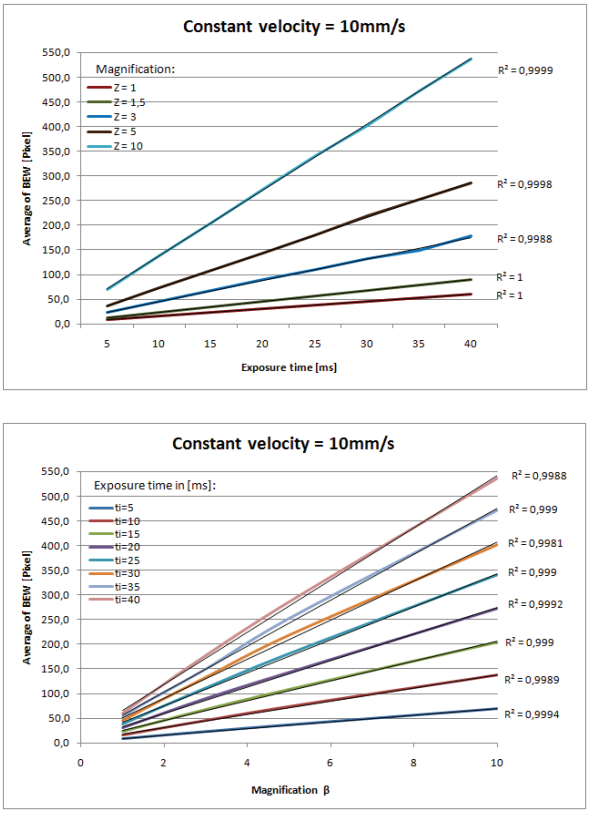

Fig. 4. Average BEW as a function of exposure time and magnification for a predefined velocity at 10mm/s

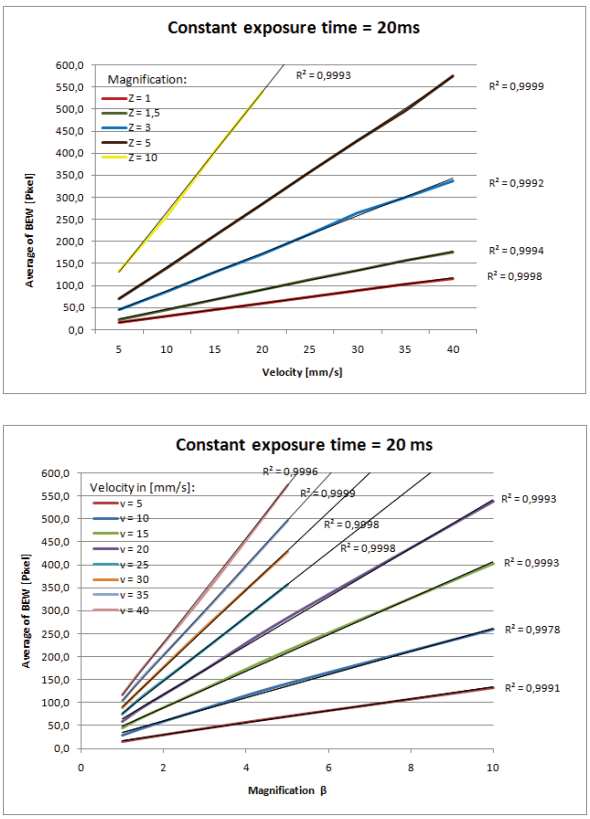

Fig. 5. Average BEW as a function of velocity and magnification for a predefined exposure time at 20ms

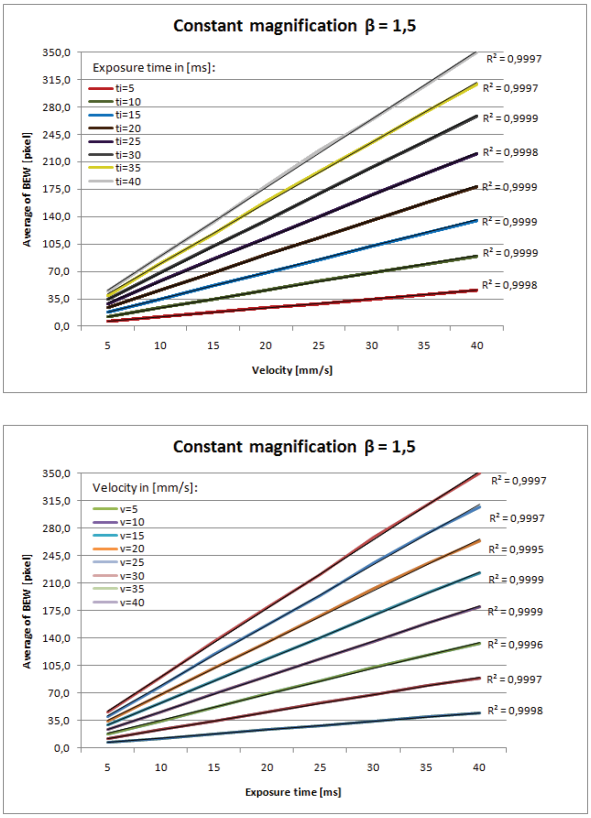

Fig. 6. Average BEW as a function of velocity and exposure time for a predefined magnification at 1.5

Every figure presents the average of BEW as a function of the other two CMM parameters respectively. The measured BEW are represented in the colourful lines and then are used to fit the trend line according to linear regression analysis. R^2 denotes the R-squared value or coefficient of determination, which is a measure of the degree of correlation between the dependent and independent variables. A trend line is most reliable when its R^2 value is at or near 1.

The trend line is drawn as the thin line in the chart and represents the measured BEW that is written as BEW_{meas}. From Fig. 4, 5 and 6, it has been observed that, for each predefined parameter, the measured BEW_{meas} varies linearly with the other two parameters separately:

$$\begin{aligned} BEW_{meas} &= \kappa_1 . V + c_1 \\ BEW_{meas} &= \kappa_2 . \beta + c_2 \\ BEW_{meas} &= \kappa_3 . t_I + c_3 \end{aligned} \tag{2}$$

In (2) the velocity of CMM's stage V, magnification of lens β and exposure time of camera t_I are independent with each other, therefore (2) can be rewritten in a multi-linear form as:

$$BEW_{meas} = \kappa . V . \beta . t_I + c \tag{3}$$

The results of the experiment show that the R^2 values were always higher than 0.9978 (minimum in Fig. 5 below) and most of them higher than 0.9995.

4. DISCUSSION

4.1. Proving the theoretical model

The theoretical motion blur model in Fig.1 can be rewritten as (only for one dimension i.e. x-axis):

$$L_{bm} = \kappa . V . \beta . t_1 \tag{4}$$

From Equations (3) and (4), it proves the equation (1):

$$BEW_{meas} = \left| \vec{L}_{bm} \right| + L_{bOffset}$$

Equation (1) shows that the grade of motion blur in the image is linear to the CMM parameter.

4.2. Optimal working range of CMM's parameters in dynamic measurement

The size of CCD (charge coupled device) sensor in CMM UNI-VIS 250 is 992pixels*992pixels. The empirical value of max blurring grade L_{bm} along the motion direction (in this paper only x-axis) is about one third of whole image, i.e. 330 pixels here, the blurring grade higher than that is not propitious for the following image processing such as image restoration and edge detection.

From Fig. 4 and 5 it has been observed that there are a lot of combinations of the three parameters whose result exceeds this limit.

This limit for blurring grade varies with inspected objects. With the proposed model in (1) and (4) it is easy to determine the effective combination of the three parameters which leads to the appropriate motion blur. In this way, an appropriate working range of the CMM's parameters in dynamic measurement can be determined before measurements.

4.3. Analysis of the R^2 value for every CMM parameter

The average R^2 value for every parameter is presented in TABLE II:

TABLE II. Average of R^2 value

Parameter	Average of R^2 values
Velocity [mm/s]	99,97%
Exposure time [ms]	99,97%
Magnification	99,91%

Although the absolute values are higher than 99,9%, the comparison brings the information, that the multi linear model in equation (3) fully describes the circumstances in reality. The deviations in comparison of the three dependencies are caused by different influences. Main influences are errors caused by the optical system: non-homogeneous characteristics out of the optical axis of the system like telecentricity errors, optical aberrations and distortions. Other influences came from the CMM motor control characteristics and from calibration errors. These influences are systematical and stochastic errors.

4.4. Motion blur in 2 dimensions with an angle θ

The angle θ of the motion blur in CMM can be computed as follows regarding the theoretical model in Fig.1:

$$\theta = \arctan\left(\frac{L_{bm\_y}}{L_{bm\_x}}\right) = \arctan\left(\frac{V_y}{V_x}\right) \tag{5}$$

Because of the high performance and high accuracy of CMM, the angle θ can be also computed accurately.

As known, motion blur PSF is a function of the angle θ and the distance L_{bm} of motion along θ, written as follows:

$$PSF = f(\theta, L_{bm}) \tag{6}$$

After θ is determined through (5), a search line is set along θ in the image to measure the BEW. Then, L_{bm} is determined by equation (4). In this way a 2 dimensional motion blur PSF can be accurately generated.

The advantage of generating PSF in this way is the possibility to determine a common PSF, which includes motion and out-of-focus information. The motion information in this case is determined by the proposed model approach and the out-of-focus information is determined by the estimation from Equation (1).

5. CONCLUSION AND FUTURE WORK

The experimental study of motion blur in CMM proves that the grade of motion blur in the image is linear to the CMM parameters, such as the velocity of CMM's stage V, magnification of lens β and exposure time of camera t_1. And this relationship is described in mathematical model (2) and (4). These models can facilitate the dynamic measurement in CMM. Furthermore these model helps enerate the motion blur PSF which is used to restore the motion blurred image.

The future work is the refined determination of the parameter in equation (4), i.e. $Offset$, because it is important for the generation of PSF, which is the key for deconvolution.

6. ACKNOWLEDGEMENT

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