

A FLATBED SCANNER AS A PLATFORM FOR CALIBRATING LINE SCALES

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Abstract – In the Metrological laboratory for angle and length calibration, we are developing a new procedure for calibration of line scales. The line scale is scanned with a standard computer flatbed scanner. Distances between the lines on the scale are calculated as a product of measured number of pixels and the scale factor expressed in pixels per mm, while the scale factor is determined by a laser interferometer. The results show that this procedure complies with the accuracy requirements.

Keywords: line scale, flatbed scanner, laser interferometer, calibration, fitting

1. INTRODUCTION

The Metrological Laboratory for Angle and Length Calibration, operating within the University of Belgrade, Faculty of Civil Engineering, is accredited by Serbian Accreditation Body according to ISO 17025 standard. Our accreditation scope comprises all instruments used for geodetic/surveying measurements. Also, we calibrate the line scales of different lengths for the needs of other customers.

Our procedure for calibration of the line scales proposes a comparison of the lengths between the lines of the line scale division with the laser interferometer. We perform direct, manual measurements of the line scales' division by the laser interferometer. The propagation of line scale's errors is estimated after the comparison of the nominal values of the line scale's division with the measured ones.

The procedure is straightforward and it gives good results. However, the estimation of the certain division line, since it is performed manually, introduces an operator aiming error, which depends on the operator.

Improvements of calibration methods for length measuring devices go to the direction of minimizing the influence of an operator, which leads to automatic recognition of the characteristic shapes of the tested objects. This is performed by introducing CCD cameras [1] or CCD microscopes [4,6] to the identification process.

The low-cost flatbed scanners are already used in roughness testing [3]. In this paper, we tested the possible ways of using them for calibration of the short length measurands, like line scales. The new procedure should be faster and independent from the errors arising from the operator physical characteristics.

Some experiments on calibration of line scales with flatbed scanners were already conducted, with the conclusion that the measured spacing of the graduations of

the tested glass line scale varied in patterns depending on its position relative to the scanner and the scanning direction [5]. We assumed that it came from the imperfection of the line scale mechanism, so our research was directed to estimation of the polynomial characteristic of that imperfection, expressed in the position of the scanning sensor relative to the starting scanning point.

The imperfection of the scanner rules is already known in astronomical community. The preservation of the photo plates with sky images is performed by the flatbed scanners. The improvements of the scanning characteristics, in the meaning of the positional accuracy, are made by applying the high precision measuring scale rulers [7].

2. BACKGROUND AND METHODS

2.1. A calibration target

The line scales that we usually calibrate have the millimetre division and accuracy of 0.1 mm. According to that, we need a method that could provide such model which assures the results with the accuracy negligible to the accuracy of the measurand.

The best performance that standard flatbed scanners, used for scanning office documents, can achieve is 4800 dpi. It means that the nominal value of one pixel (scale factor of the scanner) is:

$$s = \frac{25,4 \text{ mm}}{4800 \text{ px}} = 5,29 \text{ } \mu\text{m} \quad (1)$$

In order to determine the real millimetre value of a pixel, we have constructed a special arm, tightly connected to the moving laser interferometer prism. The arm ends with a target that is put on the scanner surface.

Fig. 1 shows the scanned image of the calibration target. Picture (1) depicts the whole target, while (b) represents the target centre, which is, actually, used for determination of the calibrated place of a spot on the scanner.

2.2. Linear positions of the calibration target

The procedure applied for the determination of the linear positions of the calibration target is shown in Fig. 3.

The arm is tightly mounted to the interferometer moving prism. The scanning procedure in resolution 4800 dpi, for an A4 format object, lasts up to ten minutes, depending on the applied scanner. For that reason, we have scanned only one narrow strip, to cover the target.

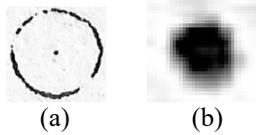


Fig. 1. (a) Calibration target, (b) Target centre

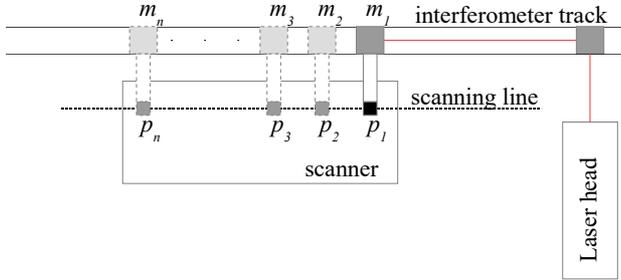


Fig. 2. The linear positions of the calibration target

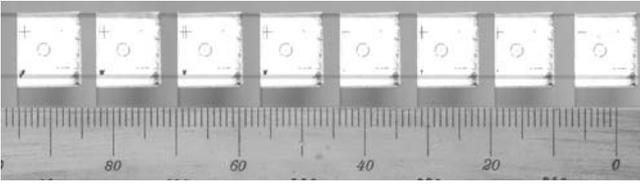


Fig. 3. A part of the calibration scan

The scan starts in point 1. The interferometer shows the reading p_1 , expressed in mm. The position of the target centroid (as shown in Fig. 2) is calculated and expressed in pixels. As soon as the scanner sensor scans the whole target, the moving prism with the arm is manually moved to the position 2. The procedure repeats for all n positions. The final scan of the scale with a set of scanned targets is depicted in Fig. 3. The distance between the adjacent target scans varies, due to manual movements. However, their positions are determined with the accuracy of $0,5 \mu\text{m}$, which is the accuracy of the distance measurement of the laser interferometer.

2.3. Determination of the centroid of the target image

Since the shape of the target image is not a perfect circle, an issue of estimating its centroid arises throughout the experiment. The centroid of the image can be calculated using two different techniques: (1) the image moment analysis and (2) profile fitting or point spread function (PSF) fitting [2]. We decided to use the first one, the method often applied in astrometry applications, when there is a need for determination the centroid of the image of a star in a digital image of the sky.

The sum of the integer powers of the pixel values are considered as the moments of the image. The $(K+L)$ moment for the digital image is defined as:

$$B_{KL} = \sum_x \sum_y x^K y^L B(x, y), \quad (2)$$

where x and y are image coordinates of the particular pixel, and $B(x,y)$ is the intensity of grey level of that pixel. For a 2D case, which is needed here, two moments are defined:

$$B_{10} = \sum \sum xB(x, y)/B_{00}, \quad (3)$$

$$B_{01} = \sum \sum yB(x, y)/B_{00}. \quad (4)$$

In equations (3) and (4), B_{00} represents the total intensity of the image.

The variance is defined by the second moment of the centre of the mass, which is expressed by the following equations:

$$\sigma_x^2 = B_{20}^C = B_{20} - B_{10}^2, \quad (5)$$

$$\sigma_y^2 = B_{02}^C = B_{02} - B_{01}^2. \quad (6)$$

2.4. Modelling the scanner scale factor

The scale factor of the scanner is the value that represents the real value of the pixel expressed in mm. We tried several different polynomial models (1st, 2nd, and 3rd order), estimating which one the best fits the characteristics of the applied scanner.

2.5. Calibration of the line scale

After estimation of the scale distribution model for the scanner, we performed the calibration of the line scale. The line scale is scanned in the same resolution (4800 dpi). For each centimetre of the line scale's division, i.e., the centroid of its scanned image, a appropriate pixel value is calculated.

Applying the scale factor model, we calculated the millimetre value for each cm centroid. In that way, we can calculate the differences of each nominal cm value and the measured one.

3. RESULTS AND DISCUSSION

3.1. Uncertainty of the target image recognition

The scans of the adjacent positions of the targets were mutually different. The reason of the difference is the imperfection of the applied flatbed scanner. This phenomenon implies the existence of the aiming error, i.e. the possible error of the target centroid coordinates determination which could be not negligible to the standard of the tested line scale.

In order to estimate this effect, we planned to perform seven scans of the target placed in the same position. Having seven scans of the same image, we could calculate the centroid of each image, compare the results, and estimate its measuring uncertainty.

It was slow and not efficient to scan the whole surface of the scanning area (A4 in the case of the applied scanner). Instead, we limited the scanning area just to cover the target. Furthermore, in order to minimize the possible operator error of defining the region around the target, we decided to calculate the centroids of two close target markers, separated about 1 cm one from another. The tested quantity is, then, the distance between two target centroids, expressed in pixels and μm .

The centroid coordinates are calculated according to (3) and (4). Prior to the centroid calculation, we inverted the

grayscale scans of the targets, in order to get bright spots on a dark background. The results in the Table 1 show that the uncertainty of the target centre recognition, i.e. the feature of the scanner imperfection is, having in mind (1), 10,38 μm , which is negligible to the a-priori standard of the line scales that would be calibrated by this method (0,1 mm or more).

Table 1. Determination of the target centroid

N°.	Y1	X1	Y2	X2	Dp	Dm
	[px]	[px]	[px]	[px]	[px]	[μm]
1	1055.6	2183.3	1078.5	4064.8	1881.7	9954.4
2	1567.5	2181.7	1591.6	4064.0	1882.5	9958.3
3	1565.7	2186.8	1591.6	4067.0	1880.3	9946.9
4	2027.8	2182.7	2051.5	4062.2	1879.6	9943.2
5	1566.5	2186.3	1592.5	4070.6	1884.5	9969.0
6	1917.8	2187.2	1942.2	4069.5	1882.4	9958.0
7	1744.0	2187.8	1767.8	4072.5	1884.9	9971.2
average					1882.3	9957.3
standard deviation					1.96	10.38

3.2. The calibration model of the scanner

The first model that we applied for modelling the scanner calibration was the linear, first order polynomial fitting. After obtaining the coefficients for the polynomial, we calculated the residuals from the nominal values in measured points. The result is presented in Fig. 4. Although the scaling factor (pixel to mm ratio) was calculated with the accuracy of 0,53 $\mu\text{m}/\text{pix}$, the residual diagram shows that the linear model does not comply to the scanner error distribution model. The largest residual is 0,13 mm, which is larger than the accuracy of the measurand that should be calibrated.

The second model we applied was the second order polynomial fitting. Now, the differences from the nominal values fall into the interval (-0.03, 0.05). This is presented in Fig. 5. This model fulfils the accuracy requirements. All residuals fall within the interval of confidence that assures its negligence of its error to the nominal error of the measurand that would be calibrated using this method.

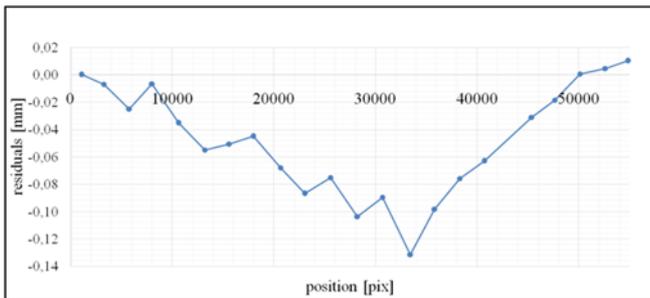


Fig. 4. Residuals from the 1st order polynomial fitting

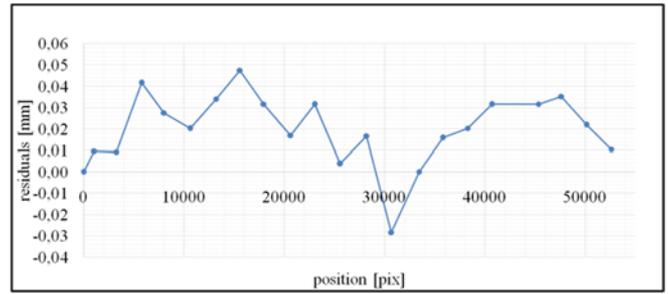


Fig. 5. Residuals from the 2nd order polynomial fitting

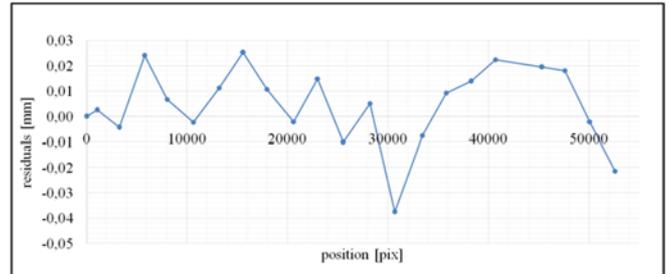


Fig. 6. Residuals from the 3rd order polynomial fitting

However, we tried the 3rd polynomial model, also. The graph of residuals concerning this model is presented in Fig. 6. All values are within the interval (-0.04, 0.03). After examination of Fig. 5 and Fig. 6, we preferred the 3rd polynomial fitting for the calibration model for this particular scanner.

3.3. Calibrating the line scale

We tested our procedure on calibration of the steel line scale 250 mm long. The line scale has two divisions, 1:1000 and 1:2000, and is used in mapping purposes.

We performed two scans of the line scale. Both scans are processed with the 3rd order polynomial coefficients. Diagrams of line scale's characteristics, obtained from two separate calibrations, are drawn in Fig. 7.

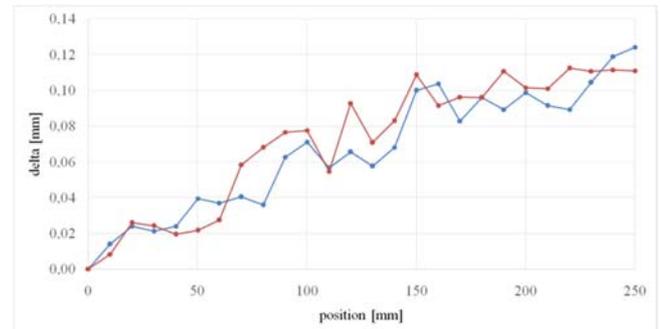


Fig. 7. Propagation of the line scale's error in two separate calibrations

To estimate the quality of calibrations, we constructed a graph of differences of the residuals from two calibrations. This graph is depicted in Fig. 8.

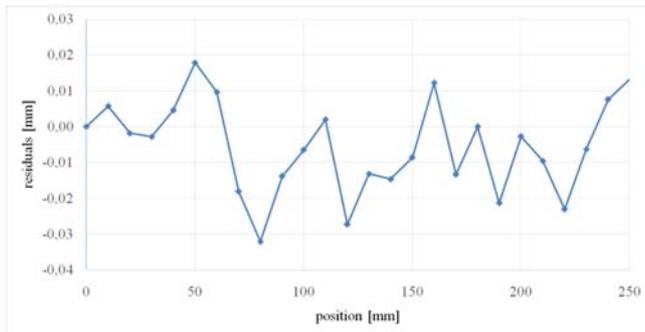


Fig. 8. Differences in residuals from two separate calibrations

The differences between two independent calibrations fall between -0.03 mm and 0.02 mm, with the average of -0,01 mm and standard deviation of 0,01.

4. CONCLUSIONS AND REMARKS

The calibration procedure for calibrating the line scales using the low-cost flatbed scanners can fulfil the necessary accuracy requirements. The accuracy and reliability of the procedure depend on the scanner characteristics, which is expressed mostly in the repeatability of the scans.

Calibration of the scanner itself can be done with the laser interferometer. When tightly connected to the interferometer, the mechanical arm is positioned at the scanner surface without any influence of the operator error. No aiming error is involved in the process.

Since the low-cost scanners do not provide homogenous accuracy of the sensor positioning, we have performed the calibration along the whole scanning area, modelling the scale factor using the 3rd order polynomial fitting.

We tested the procedure by scanning the 250 mm long steel line scale with mm division. We performed two independent scans and processed them with the 3rd polynomial fitting. The differences between two calibrations are within 0,05 mm. According to the obtain result, this method can be used for calibration of the line scales.

The critical spots in application of this method are the imperfection of the scanner which leads to the low repeatability of the target image, and the possible high order polynomial change of the scanner scale in the function of the distance from the starting scanning point.

Those issues can be overcome by rigid testing of the scanner that is used for calibration of the line scales. However, in the case of the insufficient accuracy of the scanner, by joint scanning of the calibration target and the tested line scale, the scale change of the scanner becomes neglected, because it is reflected in the same way both to the target and the calibrated line scale. Our further research will be directed to investigation of minimizing of these influences.

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