ROBUST LINE DETECTION FOR LINE SCALE CALIBRATION

JOSÉ ANTONIO MUÑOZ-GÓMEZ
Universidad de Guadalajara - CUCSUR, Av. Independencia Nacional 151
Autlán de Navarro, Jalisco, C.P. 48900 MEXICO, e-mail: jose.munoz@cucsur.udg.mx

CARLOS GALVAN
Centro Nacional de Metrología (CENAM), km 4,5 Carretera a los Cues
Mpio El Marques,Querétaro C.P. 76241, MEXICO, e-mail:cgalvan@cenam.mx

A novel method for detection of lines in a digital image used in line scale calibration process is described. The line images are recorded by a moving microscope and a CCD camera. This method is based on the center of the line instead of the edges of the line. Line detection is one of the most important problems in the line scale calibration. This method uses a Gabor filter for each row in the digital image. Likewise, based on robust statistics, some outlier points due to imperfections in the mark on the scale are ignored.

Keywords: Line detection, scale calibration, Gabor filter.

1. Introduction

Historically, measurement of graduated lines scales is one of the most important tasks in the traceability chain for the measurement of the unit of length. Before 1961, the length of a meter was defined as the distance between two graduation lines on a platinum-iridium meter prototype based in Paris. The development of stabilized lasers and the methods for determining their frequencies leaded the Conference General des Poids et Mesures to redefine the unit of length in terms of the velocity of light in 1983. In practical measurements, the unit of length is often measured by using optical interferometry.

There are several instruments designed to make line scale calibration using laser interferometers, some of them use a photoelectric microscope in order to observe graduation lines. The position of the microscope (or scale) is measured by the laser interferometer [4, 5]. Those measurements can be taken while the microscope is located on the graduation line or dynamically when the

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microscope position moves through the graduation lines. Other instruments use a CCD in order to observe the line position even statically or dynamically [3, 6].

In both cases the main goal in the calibration process is to detect accurately the center of the scale mark. This work shows a novel method to determine, in a robust way, the equation of the best fitted line to the center of the scale mark contained in a digital image. This task is required when a line scale calibration using a CCD camera is made and certain discontinuities due to manufacturing process for the scale, such as scratches on the scale surface, can be found.

This kind of problems appear when scale is type I or II according with DIN 866 or JIS B 7541 Grade 0 or 1 are calibrated. With this type of scales, you cannot obtain homogeneous digital signal in CCD, so image processing procedures to locate adequately the center of line are needed.

2. Model description

The proposed scheme is based on three stages, for the convenience of exposition we consider that each image only contains one mark. Firstly, for each row in the image, we detect the centers of the mark. Secondly, based on the detected centers, we adjust (by robust statistics) a line. Finally, we establish a relation between the lines and the global coordinates. These steps are described in the following subsections.

2.1. *Center detection*

The detection of the center line for each column with a sub-pixel precision is based on the complex Gabor filter; this is a well known quadrature filter. This process is done for every row in the image. The Gabor filter is designed in space domain defined by

$$h(x)=g(x)[\cos(\varpi_0 x)+j\sin(\varpi_0 x)]\,, \qquad (1)$$

where *g(x)* is a Gaussian function with $\sigma = \varpi_0/4$. When this function is convolutioned with a signal that contains a scale mark, we obtain a signal from which the maximum magnitude estimates the center of the mark. Besides, based on the phase, we determine the center of the mark with sub-pixel precision. This process is showed in Figure 1.

Once that the maximum of the magnitude is located we look for the phase of the filtered signal for a phase zero value. We must to take into account that we are working with digital data so it makes difficult to find the exact value. For this purpose, we calculate a line (by least squares) using the values of the phase

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corresponding to the pixels located around the neighborhood of the maximum magnitude. With this procedure, we can determine the center of the line with sub-pixel resolution.

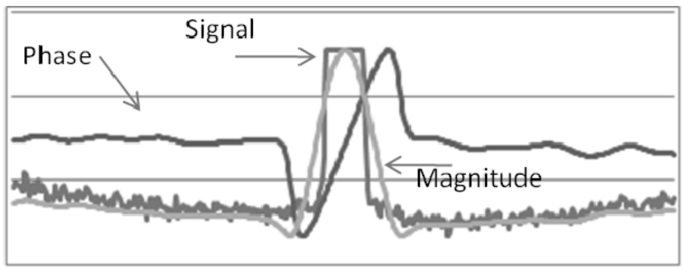


Figure 1. Gabor filter applied to a signal (noise one), and the results are the phase and magnitude.

The filter is applied for each row in the digital image obtaining the points required to estimate the line equation which describes the observed mark. When the digital image has more than one mark, this process is also hold. This can be done by making a summation of the intensity values for each column. A percentage indicating the probability to find a mark is established. With these local maxima is possible to search this position in the filtered signals.

2.2. *Robust scale mark estimation*

As a second step in the proposed scheme, is to adjust a straight line to the points located in the previous step. It is well known that the least square data fitting is sensitive to the outlier data. In the images that has been used to test this algorithm is easy to find out some outliers. For example, for the image shown in Figure 2 we can see several points that does not correctly indicate the center of the line. These points show the presence of little scratch on the scale mark.

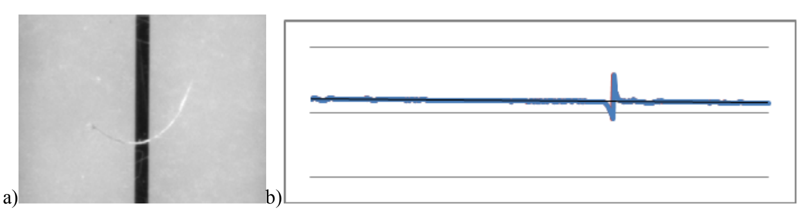
a) b)


Figure 2. a) Line Scale mark with a scratch b)Values of the center of line for each row from image 2a.

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The difference in the line mark equation parameters including all points and those outliers points eliminated manually is about 0.7 pixels.

To solve this problem we decided to use a robust estimator for the line scale equation. We propose to use an M-estimator [7]; where the goal is to determine the unknown parameters by minimizing the residual errors of the cost function.

$$U(m,b,\alpha)=\sum\rho\left(y_i-mx_i-b\right) \tag{2}$$

The truncated quadratic function ρ is described in (3), where ψ is called the influence function.

$$\rho(x)=\begin{cases}x^2 & |x|<\alpha\\ k & \text{other wise}\end{cases} \qquad \psi(x)=\begin{cases}x & |x|<\alpha\\ 0 & \text{other wise}\end{cases} \tag{3}$$

With this selection, the algorithm is similar to the original least square algorithm, but only the points which satisfy the influence function are taken into account. However, the α parameter is data dependent, so we propose an iterative method. First estimation is made with all points (regular least squares), that means α correspond to a line width percentage. In consecutive steps, this parameter can be reduced up to reach a percentage of total points. In our experiments this value is set at 60%.

Based on the procedure described above, we obtain a line equation for each mark. As result, the user is able to evaluate if the slope, for each mark, satisfy his alignment requirements.

2.3. *Robust pixel length determination*

Finally, the detected lines are necessary to map the local position (image reference) according to the global reference. For this process we use the next relation.

$$z^w = z_i + \beta x_i\,, \tag{4}$$

where z^w corresponds to the real position for *i*th-line, and β is the scale factor for each pixel in CCD. This process takes interferometer readings and positions for the same line along calibration process (in practice, the first line is taken for different images along CCD interval, in order to determine this factor) this number β is calculated solving the following equation system.

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$$z_0 + \beta x_0 = z_1 + \beta x_1 = \ldots = z_n + \beta x_n = z^w \tag{5}$$

To solve (5), we decide to continue with robust statistics by using an M-estimator with a function (Hampel) depicted in eq. (6).

$$\rho(x) = x^2 \big/ 2\left(1 + x^2\right) \tag{6}$$

Using this function the optimal value for the factor β is found by minimizing the cost given by

$$\min_{\beta}\left\{U\left(\beta\right) = \sum_{\langle 1,k\rangle \in C} \rho\left(z_k + \beta x_k - \left(z_i + \beta x_i\right)\right)\right\} \tag{7}$$

With the factor β and the sensor coordinates, the center of each mark is mapped to a global coordinates obtaining the distances for all graduated lines. In [1], the scheme proposed is described in more detail. Also, in [2] the mechanical system is showed.

3. Results

The purpose of this section is to test the proposed method. We exemplify the algorithm by analyzing two cases. This method has been used in the CENAM´s line scale calibration bench [2]. This instrument uses a laser interferometer to measure the position of a Vision System from digital images are obtained. These instruments are used by CENAM to calibrate different kind of line scales, eventually is also used to calibrate measurement tapes. The results depicted in this section do not consider the errors of the mechanical system, because they are not considered in the proposed model.

In Figure 3 we show different types of images that can be seen in the calibration process. In Figure 3a the edges of the line are well defined, on the other hand, Figure 3b shows several little scratches around of the edges in each mark.

For images like those shown in Figure 3a (1mm scale resolution), a standard deviation about 40 nm are obtained. Pixel length is about 3.2 µm, this value is obtained with a standard deviation of 32 nm. In the Figure 3b, a standard deviation of 65nm is registered, this value is due to the scratches.

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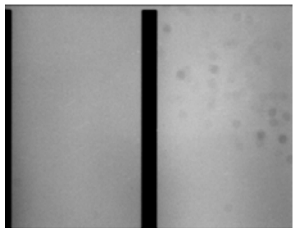
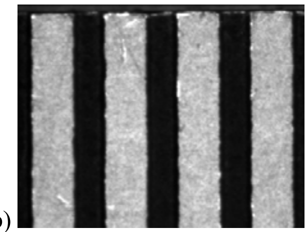
a)  b) 

Figure 3. a) Glass scale according to JIS B 7541 Grade 0, b) Steel scale according to DIN 866 Type A.

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