

## STUDY OF OPTIMAL ALGORITHM FOR DISTANCE MEASUREMENTS IN COMPUTER VISION

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### ABSTRACT

This paper has the purpose of presenting a study to determine the accuracy of a method for image measurement called Null Detector. In this new method, instead of determining the distance between two borders by counting pixels or by using subpixel approximations, the image itself is shifted and the border of the object to be measured is acquired in different points of the image. By using numerical adjustments for a specific point of the image, the real location for the border is found. The advantage of this method is that the pixel length does not need to be calibrated since it does not involve counting pixels.

**Index Terms** - Null Detector, Computer Vision, Image Metrology.

### 1. INTRODUCTION

With Computer Vision, machines can make decisions by analyzing images. Its usage in any given process generally obeys the following steps: acquisition; segmentation; feature extraction; recognition; classification and decision-making [1].

Currently, Computer Vision systems are largely employed in control, monitoring and also in inspection. For control and monitoring systems, the information obtained from an image can be qualitative or quantitative, with reasonable variations. In such cases, the applications may have the purpose of evaluating a product quality in industrial environments or enhancing security systems.

In quantitative applications, measurements are extracted directly from the images, with national metrology institutes leading research into measurement by image in different areas. The measurements may vary in accuracy from tenth of a millimeter [2] to a couple of nanometers [3,4].

In high accuracy applications, the most used type of equipment are the coordinate measuring machines that use an optic probe, called simply optical CMM. They have been gaining ground in the industry due to the possibility of measuring several standards and parts which cannot be measured by contact, such as line scales, circular apertures, grids and mechanical components with small dimensions, such as gears, screws, among others [5].

This paper has the purpose of presenting a methodology for implementing a new method among several image measurement methods, called Null Detector. Measurements of graded line scales will be made using an optical CMM in order to verify the accuracy and applicability of this new methodology.

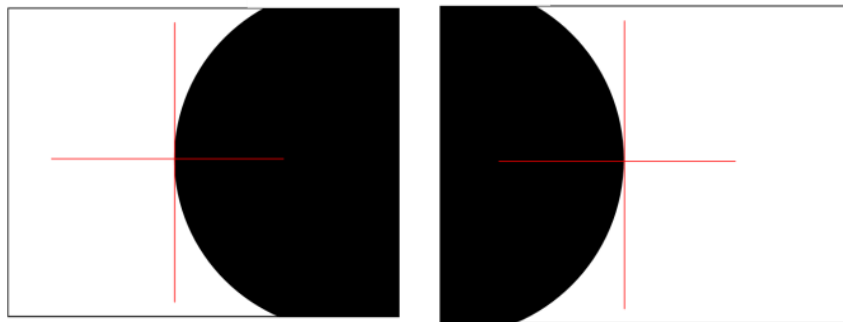
## 2. MEASUREMENT BY IMAGE

To measure an object from an image is to determine the distance between two borders of said object. This type of measurement may be accomplished in several different ways:

- Manual Method

1 - The border of the object is aligned tangent to a fixed reference, a crosshair (Figure 1). [6]

2 - Step number 1 is then repeated for the other border of the object whose measurement must be determined.



**Figure 1. Diameter measurement using a fixed crosshair.**

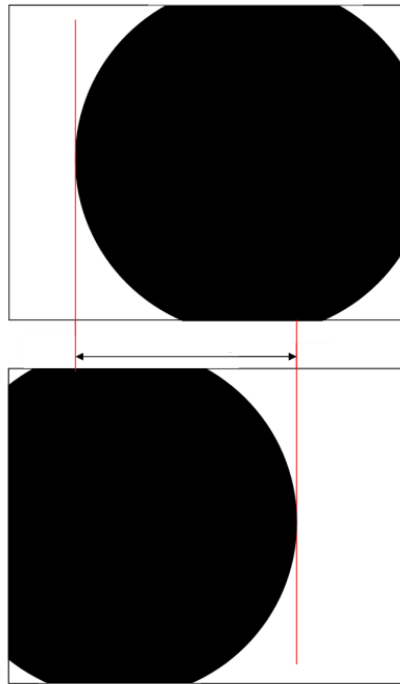
The measurement is then obtained by determining how much the object has been displaced.

- Pixel counting Method

The main disadvantages of the manual method are the operator's experience in determining the object's border is directly tied to the accuracy and the error due to the crosshair thickness. One way of eliminating the operator's influence is by using the pixel counting method [7]. In this method the measurement does not use a fixed reference in the image, but instead how much the object was displaced plus the difference between the two positions in the image, as can be seen in the example of figure 2.

1 – From the first image the position for the border of the image and the displacement are acquired.

2 – The same procedure of step number 1 is repeated in the object's other extremity.



**Figure 2. Diameter measurement by counting pixels.**

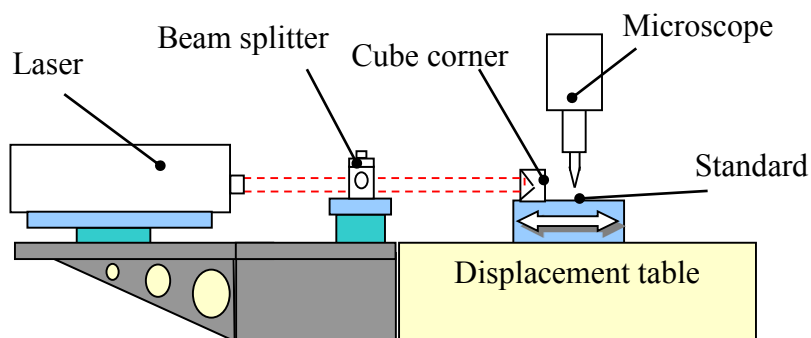
The result of the measurement is given by adding the displacement of the object in the two images and the distance between the object's edges in both images. This distance has the pixel as a measurement unit, and, to obtain it in the proper length unit the pixel must be calibrated. This is achieved by using a dimensional standard with known uncertainties, which will, thus, add another contribution for the object's uncertainty of measurement.

### **3. METHOD**

#### **3.1 Measurement system**

The Null Detector was used together with the measurement system for line scales of the Dimensional Metrology Laboratory (Lamed) of the Brazil's National Institute of Metrology, Quality and Technology (Inmetro).

The system comprises a coordinate measuring machine with an optical measurement system, as shown in figure 3.



**Figure 3. Measurement system for line scales.**

In this system, the standard is placed on the displacement table and aligned in relation to an interferometric laser. The displacements of the table are measured by the laser and are seen, at the same time, through the microscope with a magnification of up to 400x. These images seen through the microscope are acquired by a CCD camera.

### 3.2 Null Detector

The objective of the measurements with this new methodology are to eliminate the uncertainty contribution regarding the pixel calibration as means of decreasing the uncertainty of measurement as a whole for image measurement.

This methodology is an enhancement of the manual measurement previously described in item 3.1. However, instead of having an operator manually position the extremities of the object on the crosshair shown in the screen, these extremities are numerically projected to a fixed point.

For each of the object's extremities, a sequence of images is acquired, each in a different position. From every image the information for displacement and border position are extracted. With this set of data, two graphs can be plotted for pixel  $x$  displacement, one for each extremity. The sequence of points must be then fitted linearly, generating equations of the type  $L = a \cdot p + b$  where position  $L$ , in millimeters, is to be determined for a fixed value of  $p$ , in pixel, that will be used on the two fitted equations that were calculated. The difference between the values of  $L$  for the equations of both extremities is the measurement result.

### 3.3 Measurement procedure

A procedure has been designed to evaluate the Null Detector's performance by measuring a line scale of 5 mm with 1 mm as the smallest division.

For this procedure, the distances between the points of 1 mm, 2 mm, 3 mm, 4 mm e 5 mm will be measured with reference to the 0 mm point.

As stated in item 3.2, measurement with the Null Detector consists of acquiring a sequence of images. Five images were used for this test and, consequentially, five values for the displacement. When measuring the line scale, this procedure is repeated for each of the distances being measured. Thus, for every image both the pixel value for the center of the mark of the scale and the displacement value for the interferometric laser are extracted.

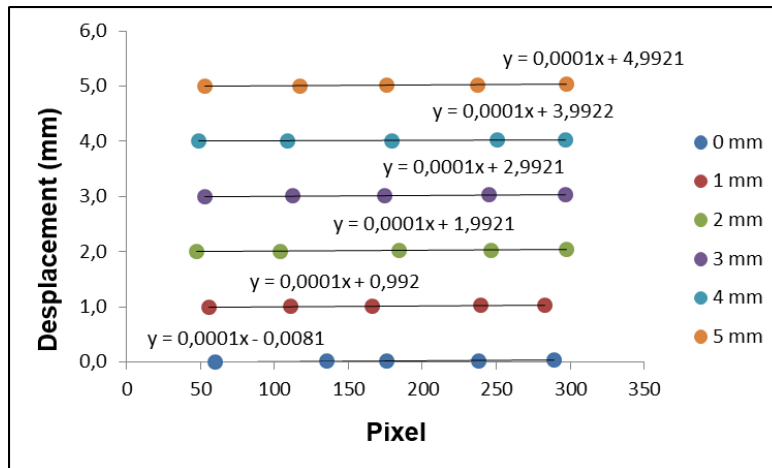
During measurement, five images are acquired and five displacement values are registered for the point of 0 mm. This is then repeated for all the other points, from 1 mm to 5 mm.

Equations for the displacement in function of the pixel value are interpolated for every measured point using the least squares method, obtaining:

$$\begin{cases} L_0 = a_0 + b_0 \cdot p \\ L_1 = a_1 + b_1 \cdot p \\ \vdots \\ L_5 = a_5 + b_5 \cdot p \end{cases} \quad (1)$$

Where the indexes 0, 1, ..., 5 refer to the traces of the scale and the value of  $p$  is the point in the image chosen so that all the lengths are projected to it.

The graph below, in figure 4, shows the five curves obtained in one measurement cycle.



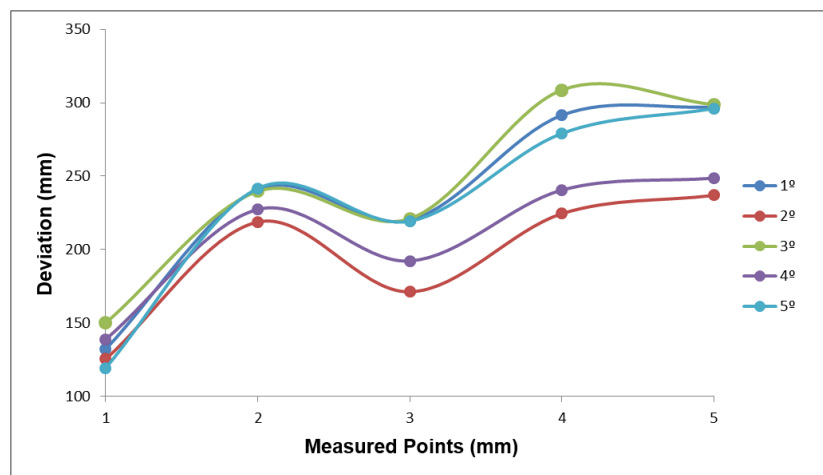
**Figure 4. Graph of the points with the equations found for all the measured points.**

Lastly, the lengths for the line scale are calculated by the difference between each calculated value of  $L$  and the value of  $L_0$ , which is used as a reference.

#### 4. RESULTS

A line scale of 5 mm, with intervals of 1 mm, was measured in different days by using both the Null Detector Method and the traditional measurement procedure for line scales of the laboratory [8].

The graph in figure 5 shows the results of 5 measurements made in five different days using the Null Detector Method.



**Figure 5. Deviation of the measured values.**

The reproducibility of the system along the time can be observed in the graph of figure 5, where the biggest differences found are of approximately 60 nm in the 5 mm point.

Table 1 shows the comparison between the results obtained by the Null Detector and the laboratories standard procedure.

**Table 1. Comparison of results between methods.**

Conventional Method		Null Detector		Normalized Error
Deviation (nm)	U (nm)	Deviation (nm)	U (nm)	
113	80	132	50	0,20
236	80	241	50	0,05
209	80	220	50	0,11
250	80	291	50	0,44
284	80	297	50	0,14

A normalized error lower than 1 indicates compatibility between the results and it can also be seen that the uncertainties of measurement found are even lower than the ones from the conventional method [9].

In the conventional method, one of the most predominant sources of uncertainty is related to the length of the pixel, which, in this new method, is not needed. However, a new contribution for the uncertainty for this method is the one regarding the value of  $p$ , where all the lengths must be projected to. This uncertainty source is much reduced when the angular coefficients of the interpolated curves are low, thus decreasing the uncertainty of measurement as a whole.

The uncertainty component for the pixel length in the current is estimated to be of, approximately, 68 nm (for the tests shown in this paper), and the uncertainties of measurement found to be of around 80 nm. In the Null Detector method, the estimate influence of the parameter  $p$  in the results is of around 5 nm, with the uncertainty of measurement being then reduced to 50 nm.

## 5. CONCLUSIONS

The analysis of the results for the measurement of the 5 mm line scale show good reproducibility of the system, with results being stable along different days. Looking further into the mathematical model for the calculation of the distances it is possible to conclude that the angular coefficient of the curves represents the pixel length in millimeter, and that the sensitivity of this method is directly related to this coefficient.

Besides the results shown in this article, experiments were also conducted for a magnification of 100x. For this magnification, however, the angular coefficient of the curves was approximately six times greater than the shown results. This leads to the conclusion that for lower magnifications the parameter  $p$  becomes a very large source of influence in the results.

So, it can be concluded that this method provides good accuracy with the shown uncertainties with devices that will provide small values for the pixel length and, consequentially, small angular coefficients.

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