Using Hough Transform as an Auxiliary Technique for Vickers Hardness Measurement

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Abstract - Hardness measurement is commonly used in industrial applications for quality control and products conformity tests, because it is fast, cheap and relatively non-destructive. Once the main error causes in hardness measurement is the indentation, this paper presents some possible approaches to measure hardness indentation automatically. It compares the use of some computer vision techniques, including Hough transform, to detect and analyze important parameters on the definition of material Vickers hardness. We highlight the main problems involved in this measurement and comment the automatic possibilities to obtain accurate results.

1. INTRODUCTION

The hardness test is widely employed in materials research and quality control, because it is the less onerous and the fastest method to obtain some material mechanical properties [1]. However, the results of hardness measurements are subjected to an uncertainty of various parameters of the test method such as test load applied, indenter, time of load application, device for indentation measurement and the operator's skill. Therefore, it is important to minimize the uncertainty related to each parameter in the test method that can influence the final measurement, in order to assure the reliability of the resulting hardness value [2].

A hardness test consists in applying a known force using a hardened steel ball (HB - Hardness Brinell) or a diamond squared pyramid (HV - Hardness Vickers) against a test surface. The projected surface area of indentation gives the material/structure hardness (Fig. 1.). Therefore, a hardness indentation measurement consists in a diameter measurement (HB) or a diagonal measurement (HV).

Nowadays, the industry uses several methods to determinate the hardness indenter mark and the selection of the indentation measurement method varies according to the size, the automation level of the industry and also the purpose of the test. The image analysis techniques are very useful tools for the measurement of hardness indentation, since its application allows an accurate features extraction that would be impossible to extract with the employment of conventional techniques [1].

We present the results obtained by different image processing techniques applied to Vickers hardness analysis. Regarding to this study, measurements were accomplished in reference hardness indentations of standard blocks calibrated by a European primary standardizing laboratory [1]. Adopting these methodologies, the user's skill has no influence in the final hardness result.

Fig. 1. Hardness testing machines.

2. HARDNESS INDENTATION IMAGE MEASUREMENT

2.1 Overview

Physically, a hardness image consists in a gray tone pixel matrix. The first step of the system consists in applying a threshold in the image, without loss of indentation boundary information.

After the segmentation process, one can observe the indentation as a dark area, in contrast to the white background. We can notice this hardness image quality is very irregular, and for that reason one of the most important stages in an automatic hardness indentation measurement consists in an image pre-processing. This simple process can be a critical one, if we use inadequate pre-processing filters. A meticulous observation will show that the boundary of the indentation is irregular (Fig. 2). Those irregularities turn, especially for human beings, the indentation measurement more difficult and imprecise. Some Computer Vision techniques can be used to minimize the lack of clearness of the indentation borders. The implementation of those techniques allows the contour analysis of the dark image, and can be divided in three steps: 1- pre-processing and segmentation of the image; 2- recognition of the indentation; and, 3- measurement of indentation dimensions. The choice of the most appropriate method to preprocess and apply a threshold for the Vickers hardness image (indentation and background), must be sufficiently robust in order to generate images with quality.
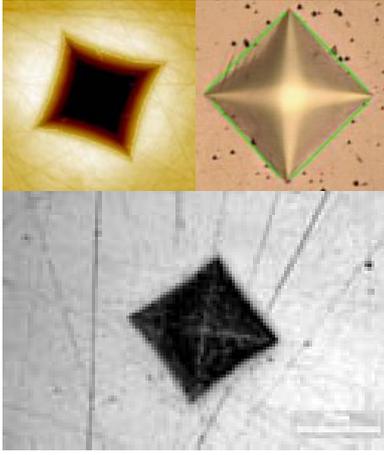
Fig. 2. Hardness indentations examples.

2.2 Hough Transform

Hough transform is an established method for shape extraction from images based on accumulator array of the most voted form. Its idea is to transform an image in a digital space (x,y) to represent it in a space of parameters $(\rho, \beta, x_0, y_0,....)$. A single point of the edge images produces an increase of n cells of the accumulator array, so all points in the same curve are mapped in an intercession cell at the parameter space. The biggest value will define the aimed curve. This method was proposed by Hough in [4] and since then many papers about this issue has been written. Firstly, Duda and Hart present an improvement of line detection using polar forms [5]. Then Kimme [6] shows an approach of circles detection using gradient information. Ellipses detection was a target of [7] in different approaches. Moreover, in 1981 Ballard [8] was pioneer in a development of generalized Hough transform and the followings [9] [10] improved the generalized transform for arbitrary set of points. However, in such generalization the main objective is more related to the pattern recognition than to shape detection because no more then an equation is searched. Nowadays, particularly linear features [12] detection, hierarchical approach on the transform [13] and non voting techniques [14] are news aspects of this.

This paper extends the use of Hough to detect individually relevant parameters on Vickers hardness form.

2.2.1 Vickers Tests

Although several papers [4] [5] have already shown straight-line detections, it is important to mention that four straight lines are considered in each Vickers tests. Lines in polar form are represented as:

$$\rho = x \cos \theta + y \sin \theta \qquad (1)$$

Equation (1) is the core in the accumulator matrix computing for straight line. It describes a line having a clock wised orientation θ at distance ρ from the origin perpendicularly. In this work (x,y) are the coordinates of any straight line searched. As the parameters (θ,ρ) are unknown, it is necessary to simulate values in ranges,

which are given by (2) and (3). Equation (2) shows the ρ's limit where N_1 is the width and the N_2 is the height of the image. Equation (3) describes the limit for possible straight line inclinations (θ).

$$-\sqrt{N_1^2 + N_2^2} \le \rho \ge \sqrt{N_1^2 + N_2^2} \qquad (2)$$

$$-\pi/2 \le \theta < \pi/2 \qquad (3)$$

Applying the Hough transform to straight lines means having a 2-D accumulator array $M(\rho,\theta)$.

2.2.2 Experimental Results

In this section, the proposed method using Hough transform is performed and consequently compared with the real values. All images are grayscale and the results are presented in pixels.

Firstly, it is necessary to process the Vickers image. In this case a low-filter followed by a threshold of level 1 is applied on the original image Fig. 3.a obtaining the processed image presented by Fig. 3.b.
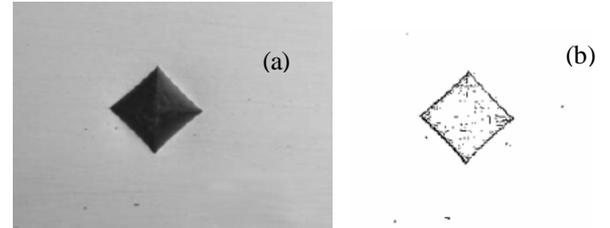

Fig. 3. Vickers hardness: (a) Original image; (b) Processed image.

The main objective of Vickers hardness test is to extract the diagonal value from a squared form in the image. In this way, we used the Hough transform, which identify the edges as straight lines providing the ρ parameter. Through this parameter provided from four straight lines, it is possible subtracting these parameters of lines whose inclinations are the same. Therefore, the size of edge is acquired and finally the diagonal is calculated. Figure 4 presents this scheme.
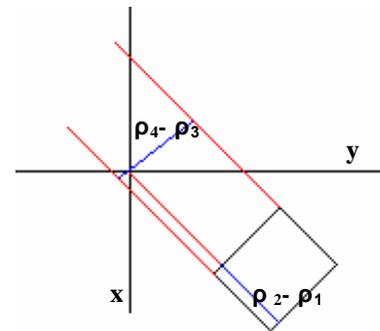
Fig. 4. Size of edge definitions.

Figure 5 shows the detection of four straight lines by Hough transform, step by step, it means, the method has been performed for four times. In addiction, after each

detection stage, parameters such as θ, ρ, and the straight line extremity are extracted and this proposed method also deletes the straight line already identified. It makes easier the next detection line. Table 1 shows all parameters extracted from Vickers image.
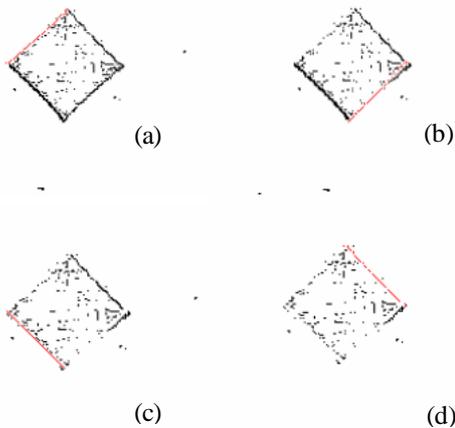

Fig. 5. Line detections from Vickers image.

θ	ρ	Initial point	Final point
40	143	(66,144)	(106,95)
40	202	(108,186)	(206,71)
-46	1	(105,97)	(150,140)
-46	-58	(64,142)	(108,185)

Table 1. Data of each line detected in HV[11].

Knowing the image magnification and the applied force during the test, we can convert the diagonal computed value (83.4 pixels) to the material hardness value (142.6 HV). So the error is 4,42%, considering the hardness true value (149.2 HV) of the calibrated standard block.

2.3 Other methods

Besides Hough transform, there are many possible computer vision techniques to obtain the medium diagonal of HV indentation. We present some of them in this topic.

2.3.1 Pre-processing and Parameters measurement

In the following methods, we should previously apply pre-processing techniques to enhance the indentation mark (Modal Threshold and a Morphological operation – closing) (Fig.6).
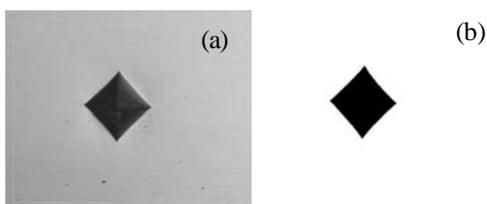

Fig. 6. Vickers hardness: (a) Original image; (b) Processed image.

We developed four methodologies to Vickers hardness test [1]: coordinates difference (CD); area (A); perimeter (P); and, detection of the indentation vertex (VD).

The vertex detection of the indentation, used in Vickers hardness, consists in obtaining the diagonal from the indentation vertexes recognition. The VD algorithm includes the following steps: 1- boundary pixels storage using TEP approach; 2- a random insert parallelogram to the indentation is generated; 3- the distance of each pixel to the nearest parallelogram side is computed; 4- a possible vertex is indicated by the greatest distance; 5- a real indentation vertex is assured by proceeding turning the parallelogram and repeating the calculation, until finding the four points that best characterize the diagonal (see Fig. 7.) [3].
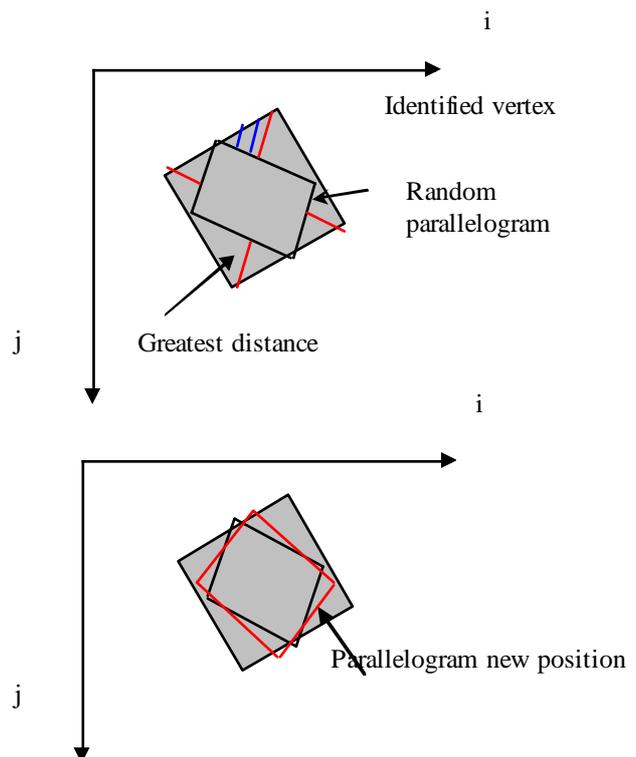

Fig. 7. Inserted parallelogram distances between the parallelogram and the indentation perimeter. The red one is the greatest distance.

2.3.2 Experimental Results

The algorithms introduced in the previous item were implemented and applied in the images obtained by hardness tests in standard hardness blocks. In the following tables we present a comparison of the obtained errors by using the developed vision techniques. In those results we consider the same image pre-processing and indentation recognition procedures, which consist in applying a global threshold and a set of morphologic filters.

The choice of the best method depends on the hardness range. In Vickers hardness, the methods DC and VP are more stable, and increasing the image amplification we can note that the error decreases [3].

For Vickers hardness, the perimeter approach presents the largest inaccuracy, this fact occurs because any

irregularity in the border contributes to increase or decrease the perimeter value (Table 2). Although the pre-processing techniques are useful to obtain best images, in the other hand, they can generate those irregularities.

	Diagonal (μm)	Error (%)
CD	143,53	4,89
A	140,14	4,28
P	113,97	28,71
VD	143,57	4,82
True Value	149,2	-

Table 2. Diagonal of HV test and errors [3].

For this image magnification the area and detection of indentations vertex methods presented the best results, and as it was expected the perimeter methodology gave the worst result, since the indentation shape is not a perfect square.

3. CONCLUSIONS

The largest difficulty in creating an automatic method, without interference of the operator, refers to the different qualities of test images, as it can be observed in Figure 2. Independent of the image nature, a system in this context should be capable to produce results with smaller errors than those obtained in conventional methods.

This paper presents a brief Computer Vision review applied to hardness automatic indentation measurement. It stands out that the choice of the pre-processing techniques adopted consists in a fundamental point for good results. The inadequate choice can take to increments or reduction of the number of pixels in the impression and, consequently, to the incorrect extraction of the diameter or diagonal. Therefore, in spite of some of the results, sometimes they possess not smaller errors than the conventional methods, it should be stood out that the absence of human being interference in obtaining of the diagonal is especially important [3]. In this context, to acquire better results we tested different image processing and analysis techniques.

According to the Hough transform, four straight lines was detected as hardness indentation and from the size of edge, it was possible obtain the diagonal.

For Vickers hardness, the area and the Hough approaches presented a competitive accuracy in comparison of the others methods. Besides, it is not so simple to choose the best automatic measurement without making exhaustive tests in different images with different magnifications and qualities.

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