
Using Hough Transform as an Auxiliary Technique for Vickers Hardness Measurement

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SUMMARY

- INTRODUCTION / OBJECTIVE

- HARNDNESS TEST

- METHODOLOGY

- RESULTS

- CONCLUSIONS

INTRODUCTION

Hardness measurement is commonly used in material research and industrial applications for quality control, that is because it is a less onerous and faster method, and also it is relatively non-destructive.

In manufacturing applications, materials are primarily tested for two reasons: either to research the characteristics of a new material or as a quality check to ensure that the sample meets a particular specification.

To a metallurgist hardness is a material's resistance to penetration.

In general, an indenter is pressed into the surface of the material to be tested under a specific load for a definite time interval, and a measurement is made of the size or depth of the indentation

INTRODUCTION

In this paper we present some methodologies to automatic measure the hardness indentation using Computer Vision techniques.

The main focus is the indentation (penetration) measurement, i.e. the hardness impression in the material surface, which is one of the principal error causes in hardness measurement.

This paper 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.

HARDNESS TEST



An indenter tip with a known geometry is driven into a specific site of the material to be tested by applying an increased normal load.



Micro-hardness tester



Example of a micro-hardness tester:
Maximum Load 10 N
Load Resolution 100 microNewtons
Maximum Depth 0-20 & 0-200 microns
Depth Resolution 0.04 & 0.3 nm

Nano-hardness tester

The Nano-Hardness test is specially suited to load and penetration depth measurements at nanometer length scales.

The Nano-Hardness test can be used in the analysis of organic and inorganic soft and hard coatings.

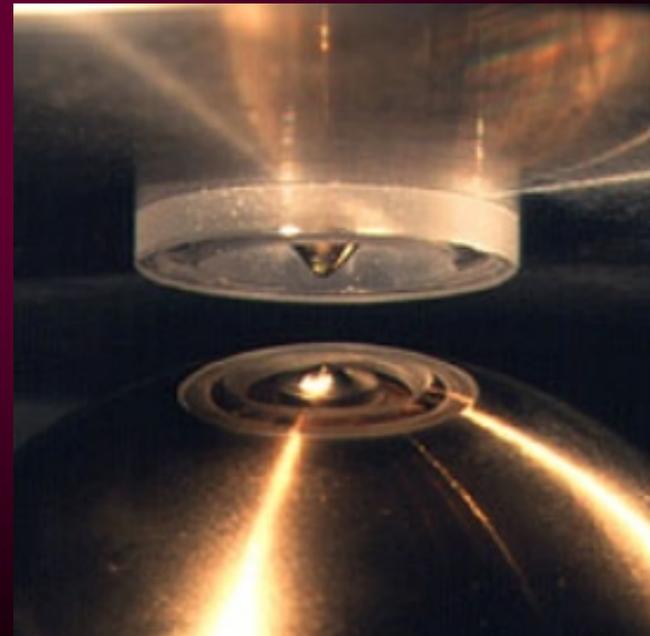
Example of nano-hardness tester:

Maximum Load 500 mN

Load Resolution 0.04 microNewtons

Maximum Depth 0-20 & 0-200 microns

Depth Resolution 0.04 & 0.3 nm

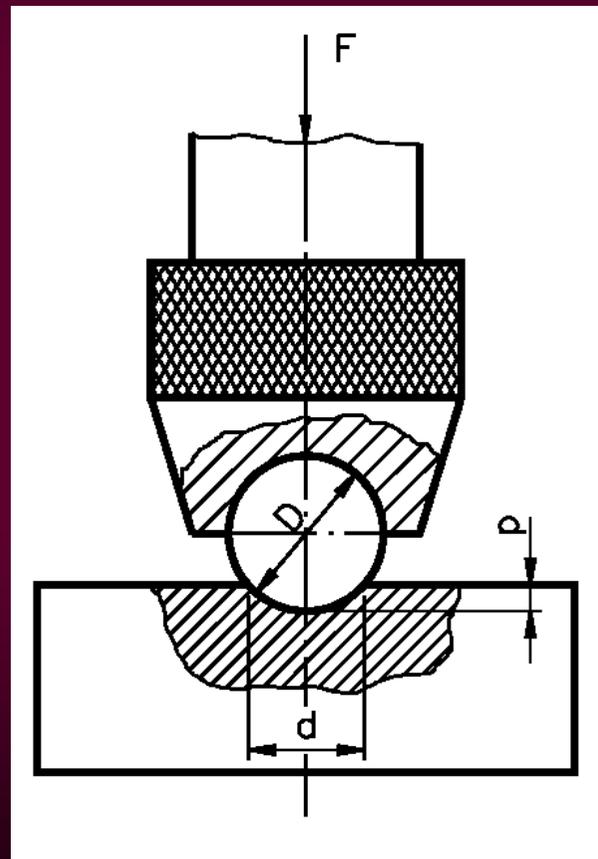


The most frequently used methods of measuring hardness involve indenting the surface of a material with an indenter of a suitable shape and material and measuring the size of the impression that results.

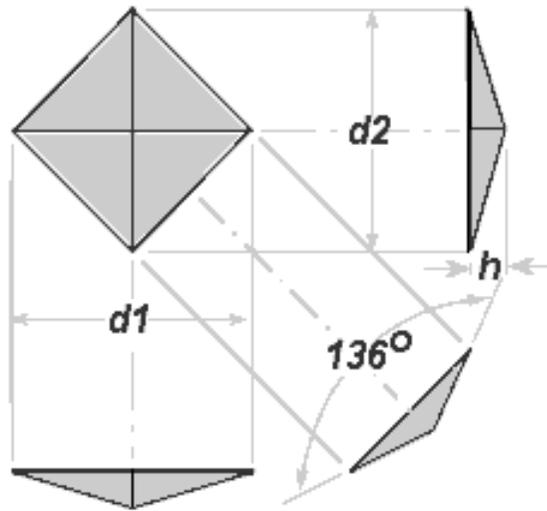
The indenters used are specially hardened steel balls (Brinell and some Rockwell scales), pyramidal diamonds (Vickers and Knoop) or conical diamonds (some Rockwell scales).



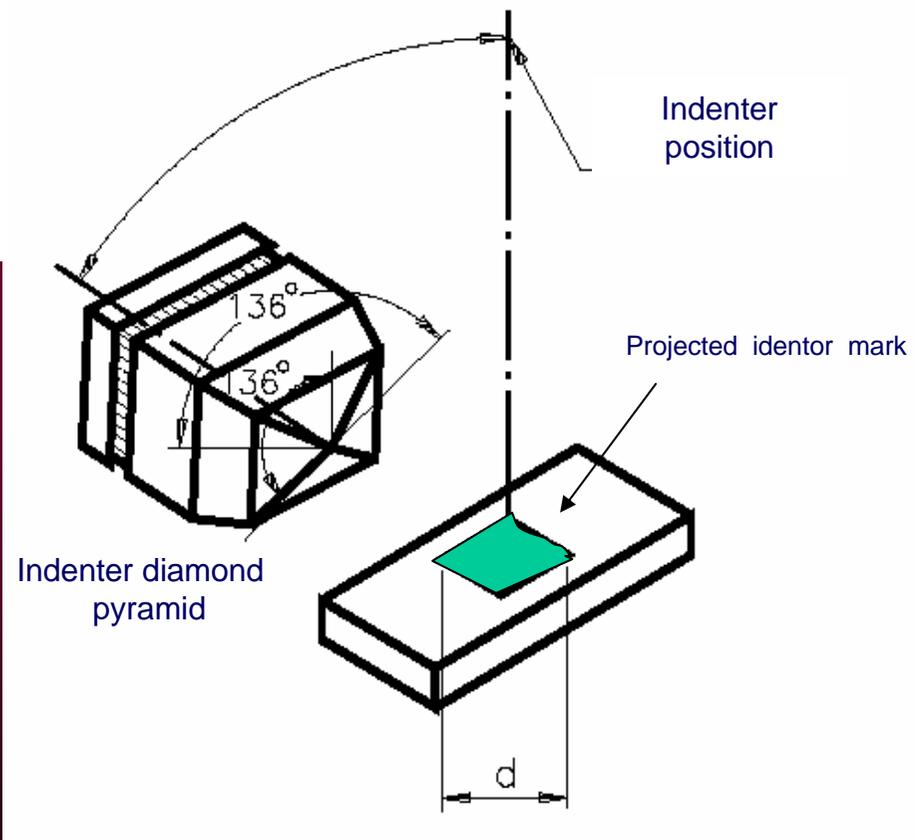
The projected surface area of indentation gives the material/structure hardness. Therefore, a hardness indentation measurement consists in a diameter measurement (HB) or a diagonal measurement (HV).



Brinell Hardness



The Vickers hardness uses a square pyramidal diamond indenter with an angle of 136° between opposite faces.

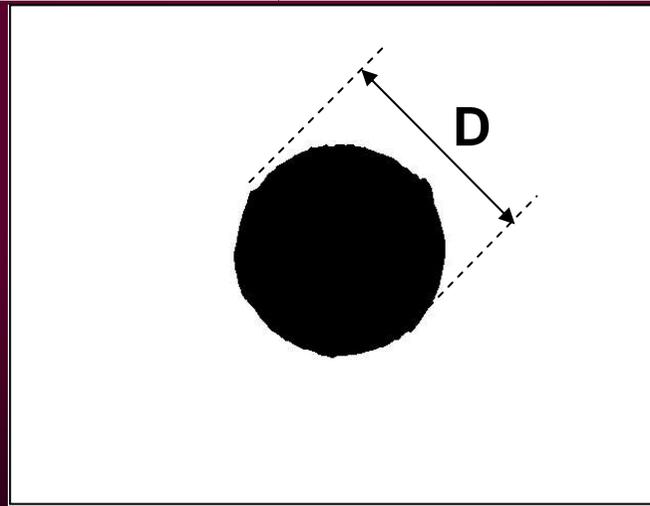


Vickers Hardness

The Brinell hardness number is given by the ratio of the load to the curved indentation area.

The diameter of the ball is usually 10mm (3/8") but can be smaller. The load used depends on the material but is usually 3000 kgf for steel, 1000 kgf for copper alloys and 500 kgf for Aluminium alloys.

$$HB = \frac{2F}{\pi D \left(D - \sqrt{D^2 - d^2} \right)}$$

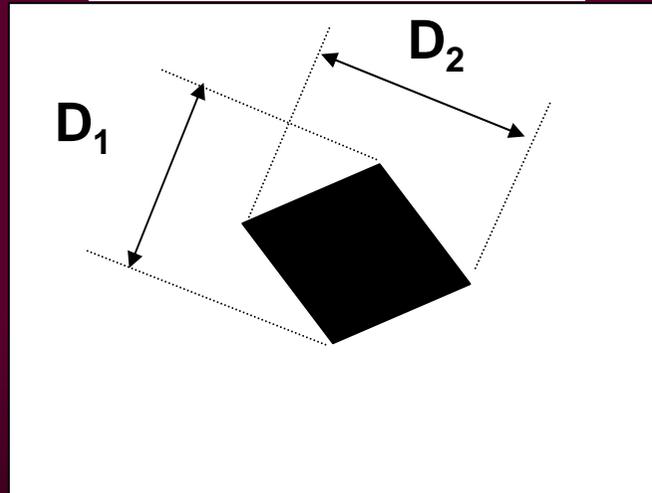


F – applied load

d – indenter diameter
D – impression diameter

The Vickers hardness is the ratio of the load to the surface area of the indentation. Loads used range from 5 to 120 kg and the indentation is measured using a low power optical microscope.

$$HV = \frac{1,8544 F}{d^2}$$



F – applied load

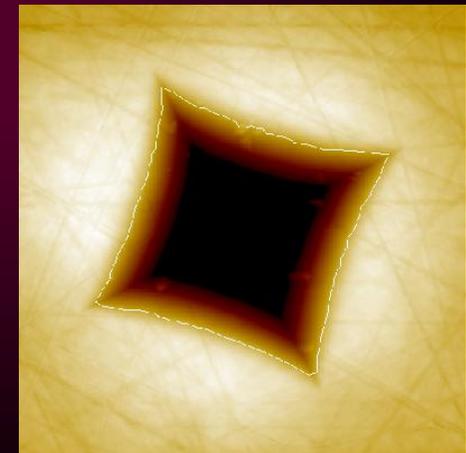
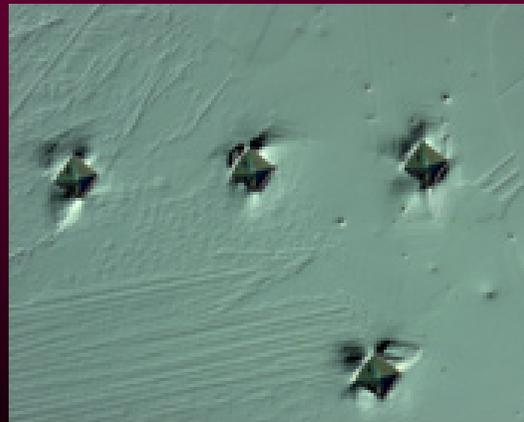
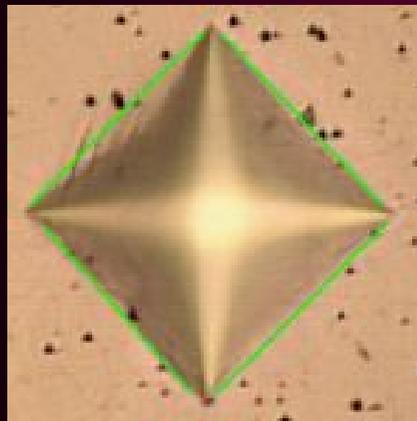
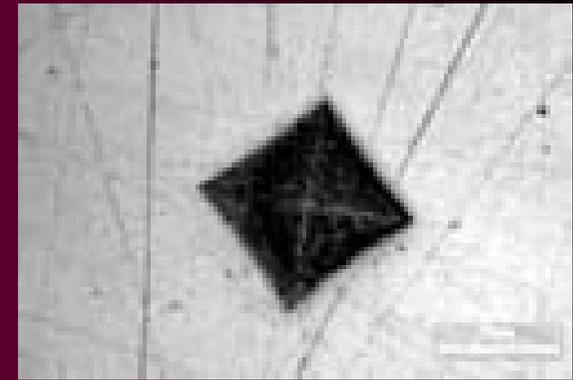
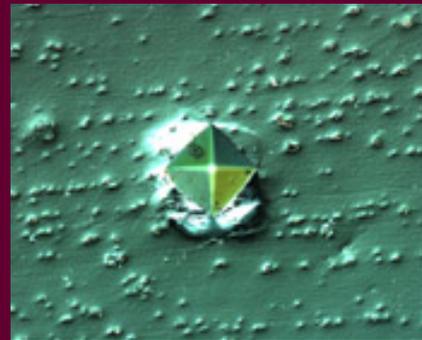
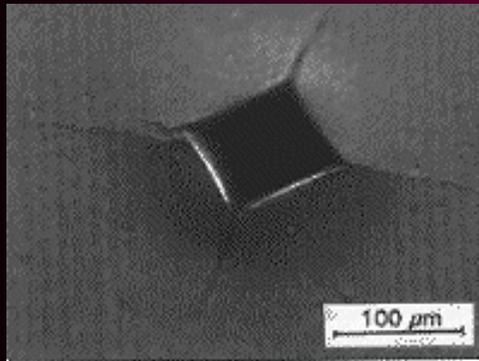
d - mark average diagonal
 $d = (D_1 + D_2)/2$

Nowadays, the industry uses several methods to obtain 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 technique is a very useful tool in the measurement of hardness indentation, since its application allows the measurement of indentation characteristics with minor errors, depending on the choosed method.

- The results are liable to errors by:
 - the applied force
 - the dimensions of the indentator
 - the loading time
 - the measurement method (its accuracy)
 - the operator's hability
-
-

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 primary standardizing laboratory



DIGITALYZING

- Images (256 gray scale / size 640x320 pixels)

- Scale

- 50x → 200 μm = 59 *pixels*

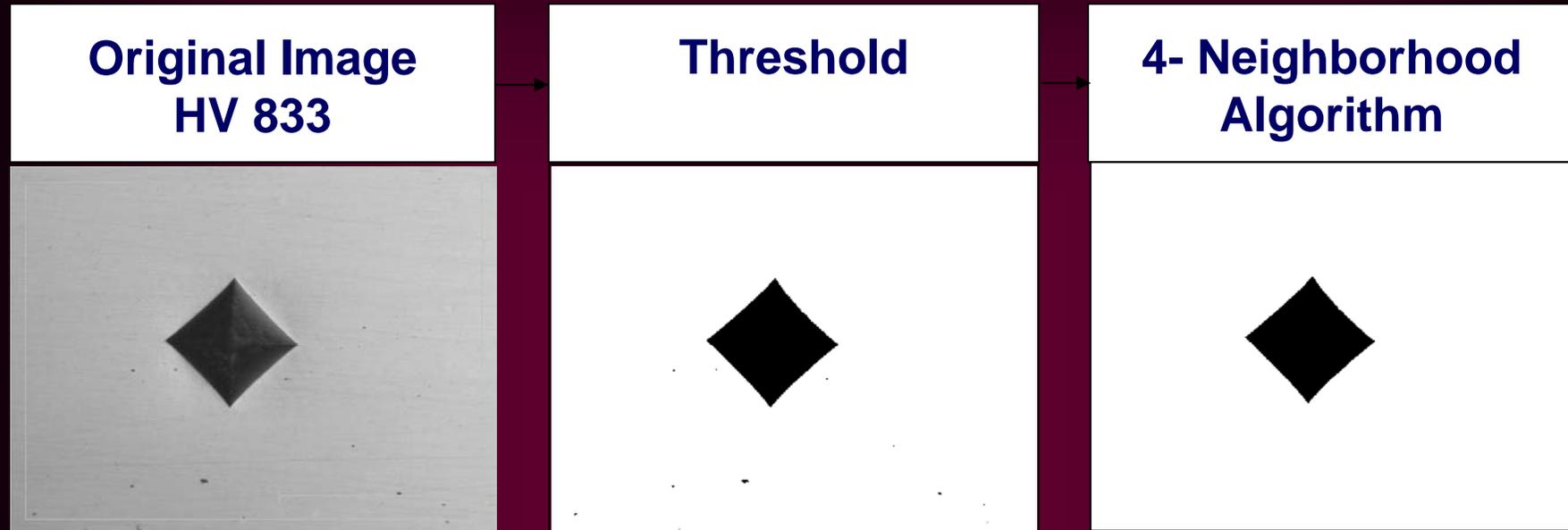
-100x → 200 μm = 117 *pixels*

-200x → 200 μm = 237 *pixels*

PRE-PROCESSING

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.

PRE-PROCESSING FOR VICKERS IMAGES



The 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. Those irregularities turn, especially for human beings, the indentation measurement more difficult and imprecise.

THE MEASUREMENT PROCESS

VICKERS

$$HV = \frac{1,8544 F}{d^2}$$

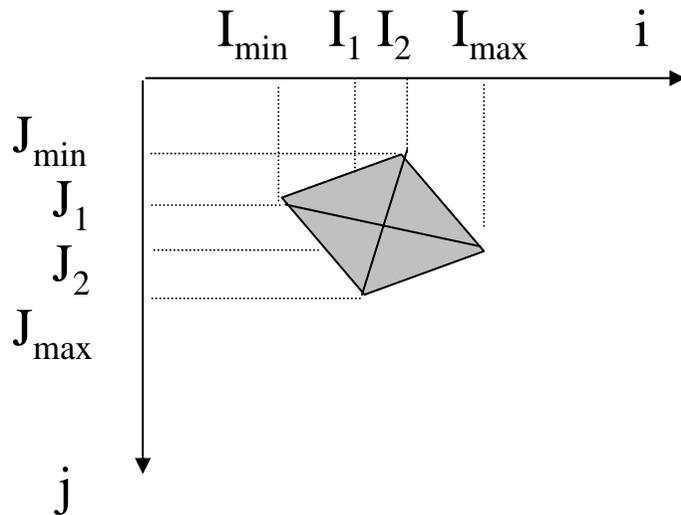
Applied Force (F) -> 10 kgf

Diagonal mean (d) -> ?

We developed four methodologies to Vickers hardness test (to obtain d): coordinates difference (CD); area (A); perimeter (P); detection of the indentation vertex (VD); and Hough transform (HT).

DIAGONALS MEASUREMENT

Coordinates Difference (CD)



$$D_1 = \sqrt{(J_{\max} - J_{\min})^2 + (I_1 - I_2)^2}$$

$$D_2 = \sqrt{(I_{\max} - I_{\min})^2 + (J_1 - J_2)^2}$$

Area (A)

| | | | | | |
|-----|-----|-----|-----|-----|-----|
| 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 0 | 255 | 255 | 255 |
| 255 | 0 | 0 | 0 | 255 | 255 |
| 0 | 0 | 0 | 0 | 0 | 255 |
| 255 | 0 | 0 | 0 | 255 | 255 |
| 255 | 255 | 0 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 |

$$Area = \sum_{i=1}^c \sum_{j=1}^l B(i, j)$$

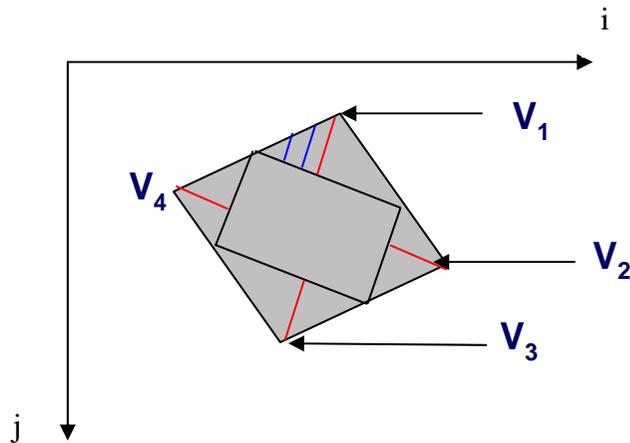
DIAGONALS MEASUREMENT

Perimeter (P)

| | | | | | |
|-----|-----|-----|-----|-----|-----|
| 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 |
| 255 | 255 | 0 | 255 | 255 | 255 |
| 255 | 0 | 0 | 0 | 255 | 255 |
| 0 | 0 | 0 | 0 | 0 | 255 |
| 255 | 0 | 0 | 0 | 255 | 255 |
| 255 | 255 | 0 | 255 | 255 | 255 |
| 255 | 255 | 255 | 255 | 255 | 255 |

DIAGONALS MEASUREMENT

Vertex Detection (VD)



$$D_1 = \sqrt{(J_3 - J_1)^2 + (I_3 - I_1)^2}$$

$$D_2 = \sqrt{(I_2 - I_4)^2 + (J_4 - J_2)^2}$$

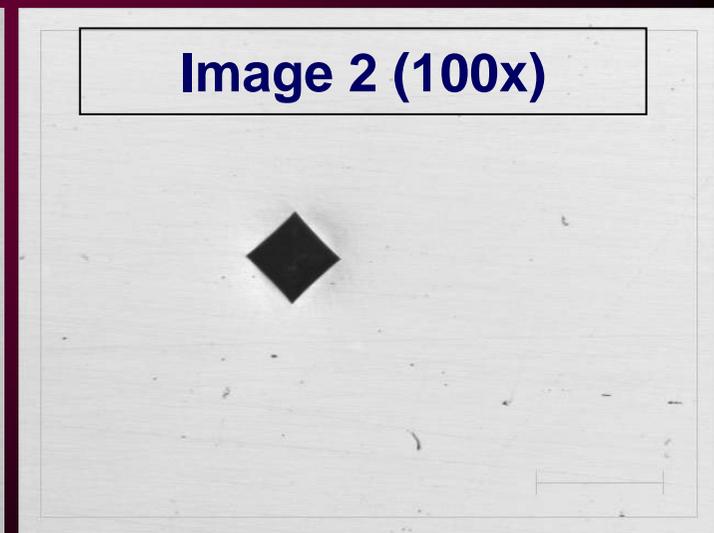
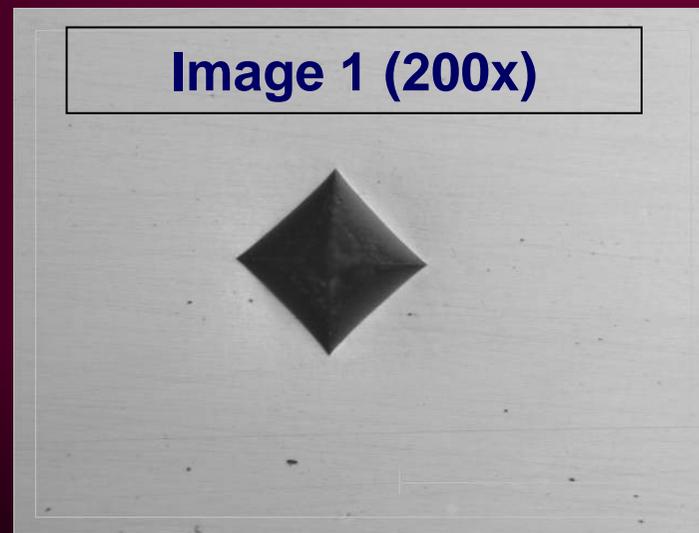
The VD algorithm includes the following steps: 1- boundary pixels storage; 2- a random parallelogram is inserted into the hardness mark; 3- the distance of each boundary pixel to the nearest parallelogram side is computed; 4- a possible vertex is indicated by the greatest distance; 5- a real indentation vertex is assured by proceeding turning the parallelogram and repeating the calculation, until finding the four points that best characterize the diagonal.

IMAGES USED

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.

**2 images
Vickers (HV833)
(F=10 Kgf)**

**Different
magnification –
the same
material and test**



RESULTS

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

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. Although the pre-processing techniques are useful to obtain best images, in the other hand, they can generate those irregularities.

VICKERS RESULTS

| Methods | Image 1 | | Image 2 | |
|---------|----------------------------|-----------|----------------------------|-----------|
| | Diag. (μm) | Error (%) | Diag. (μm) | Error (%) |
| CD | 143,53 | 3,8 | 141,9 | 4,89 |
| A | 140,14 | 6,07 | 142,81 | 4,28 |
| P | 113,97 | 23,61 | 106,37 | 28,71 |
| VD | 143,57 | 3,77 | 142,01 | 4,82 |
| TV | 149,2 | - | 149,2 | - |

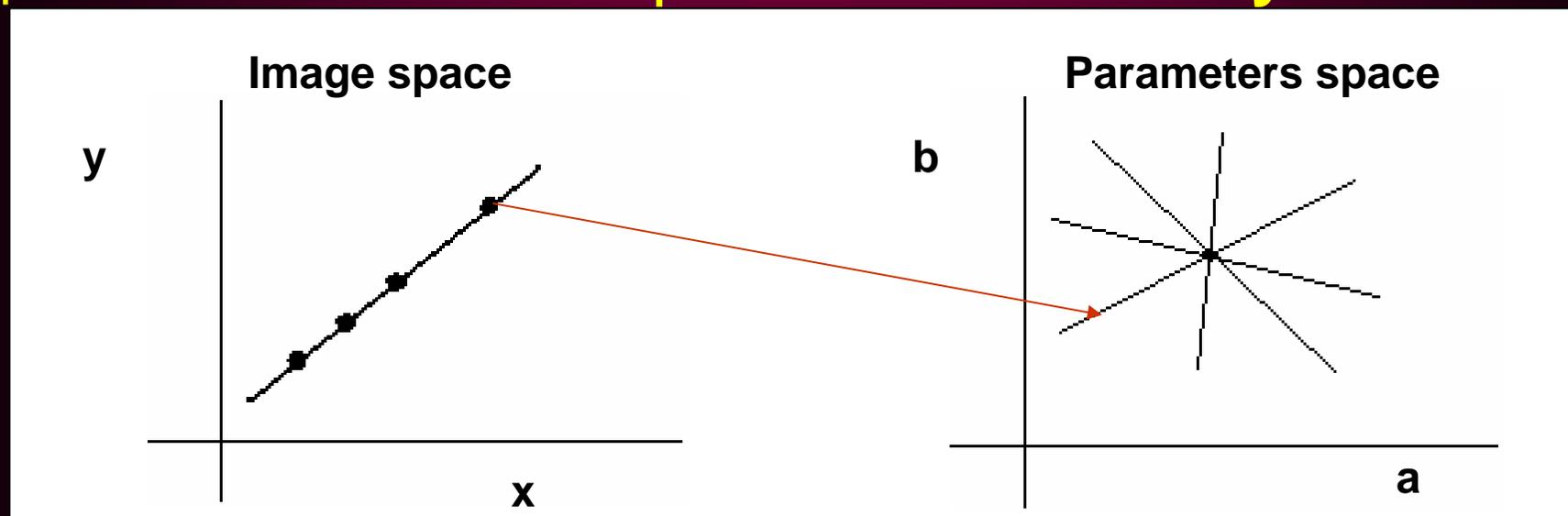
CD - coordinates difference; A - area; P –perimeter;

VD - detection of the vertex; TV – true value.

DIAGONALS MEASUREMENT

Hough transform is a method for shape extraction from images based on accumulator array of the **most voted form**, after transformation to **parameter space**.

Each point on a curve votes for several combination of parameters: General equation for lines : **$b=y-ax$**

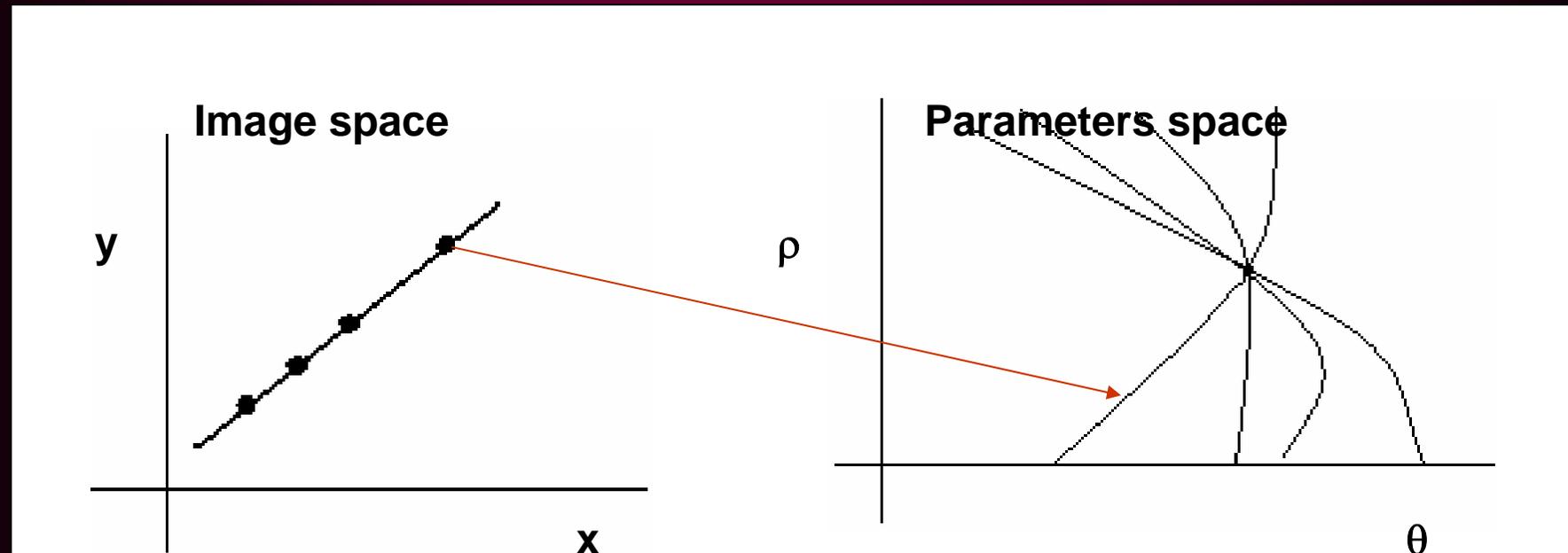


DIAGONALS MEASUREMENT

Hough Transform for lines:

In practice, the polar form to avoid problems with lines that are nearly vertical.

Polar form: $\rho = x \cos(\theta) + y \sin(\theta)$



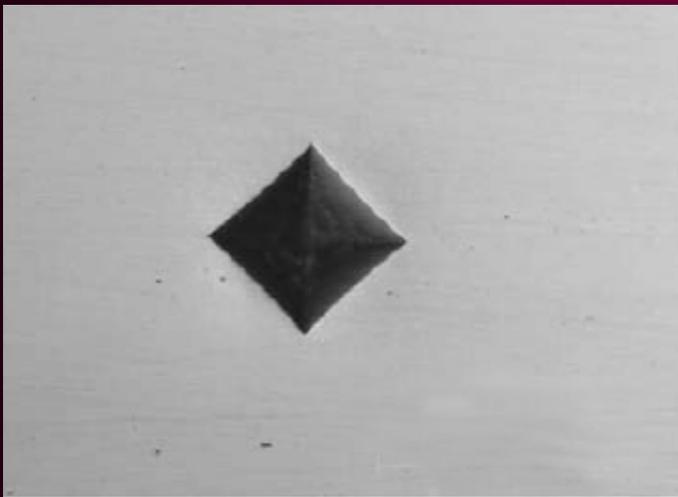
DIAGONALS MEASUREMENT

Hough Transform- Pre-processing Image

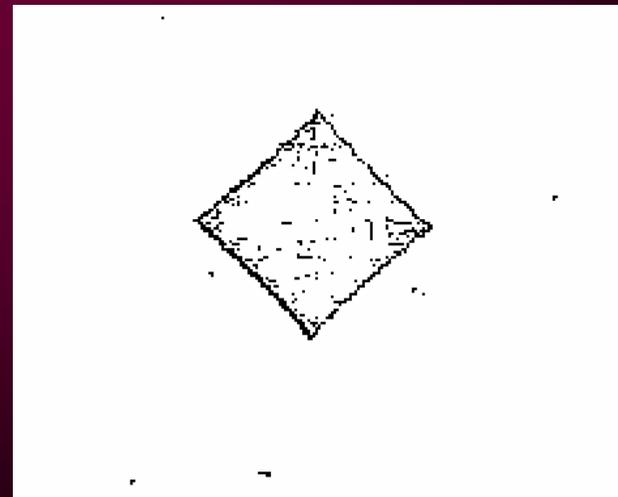
it is necessary:

a **low-filter** followed by a **threshold**.

Original Image



Low-filter + threshold

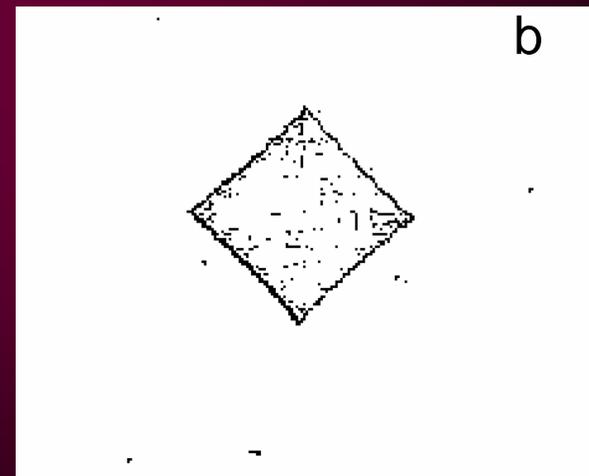
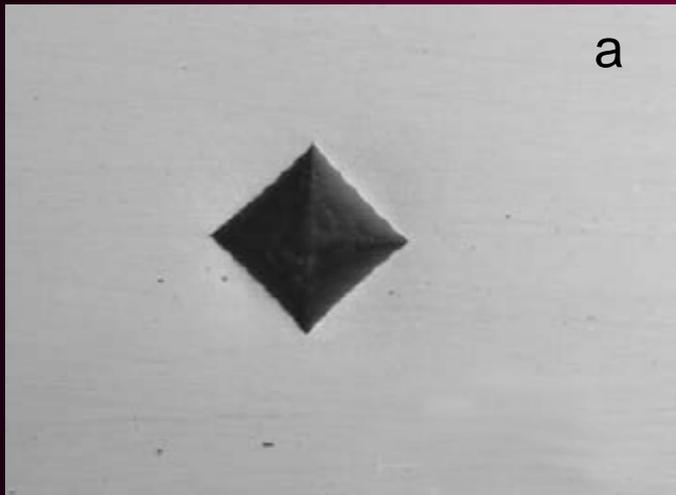


DIAGONALS MEASUREMENT

Hough Transform

All images are grayscale and the results are presented in pixels.

To pre-process the Vickers image: a low-filter followed by a threshold of level 1 is applied.

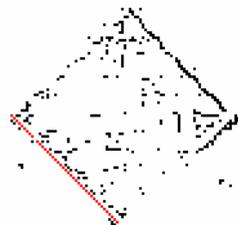


Vickers hardness: (a) Original image; (b) Processed image.

DIAGONALS MEASUREMENT

Hough Transform – Line detection

This figures can show in red each line identification.

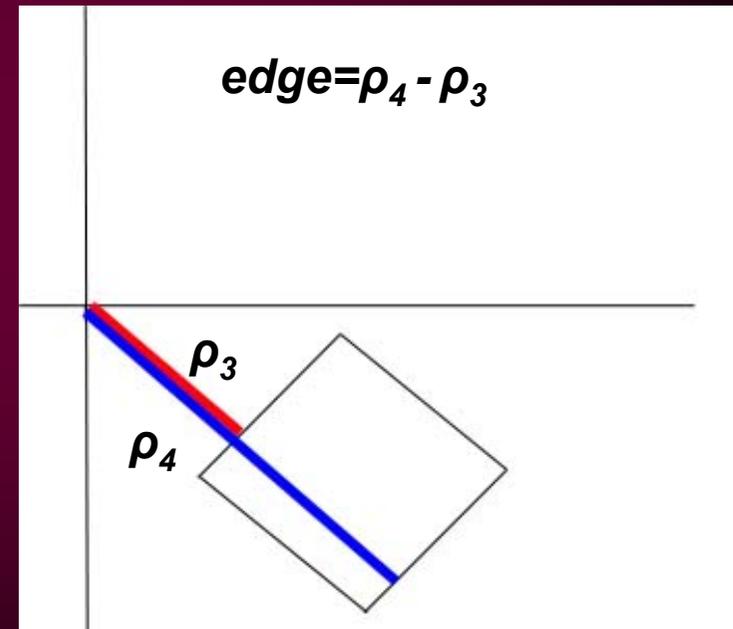
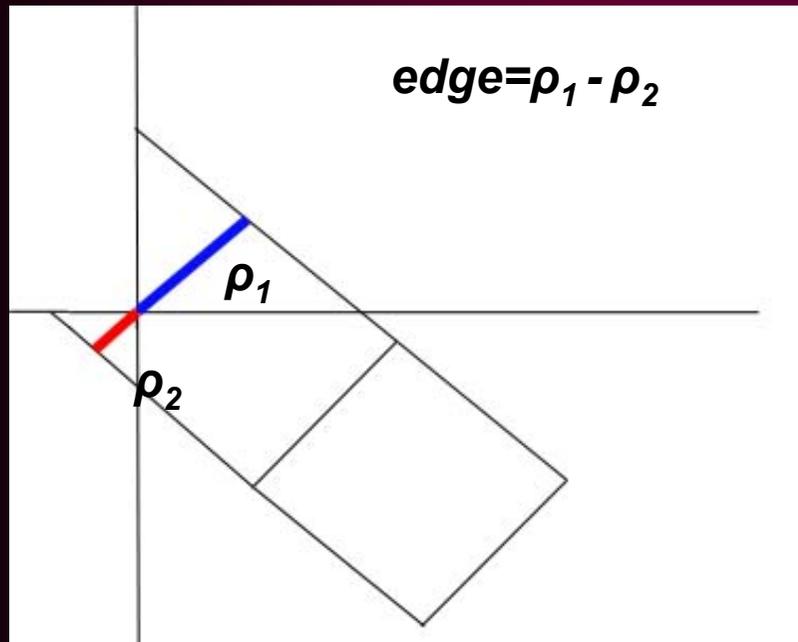


DIAGONALS MEASUREMENT

Hough Transform

ρ is the perpendicular distance between origin point and the line.

The diagonal of Vickers image can be acquired from subtraction of ρ parameter of lines whose inclinations are the same.

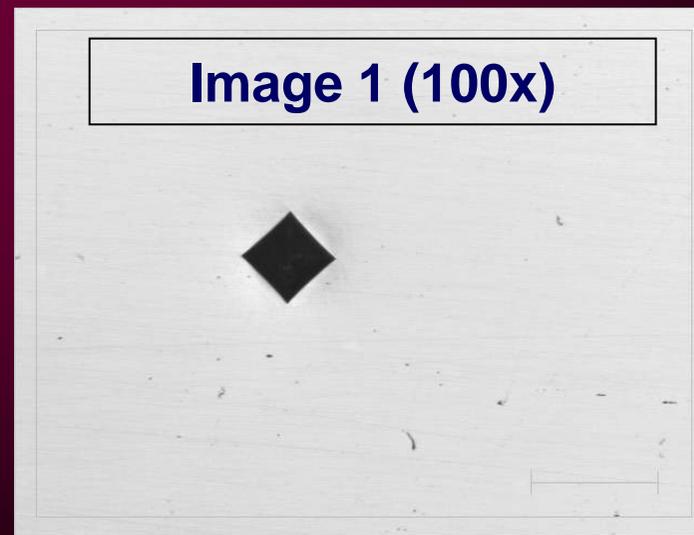


$$Diagonal = edge\sqrt{2}$$

IMAGE USED

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Images Vickers (HV833)
(F=10 Kgf)



VICKERS RESULTS

| Methods | Image 1 | |
|---------|----------------------------|--------------|
| | Diag. (μm) | Error (%) |
| CD | 141,9 | 4,89 |
| A | 142,81 | 4,28 |
| P | 106,37 | 28,71 |
| VD | 142,01 | 4,82 |
| HT | 142,6 | 4,42 |
| TV | 149,2 | - |

CD - coordinates difference; A - area; P –perimeter;

VD - detection of the vertex; HT- Hough Transform; TV – true value.

RESULTS

For this image magnification the area and detection of indentations vertex methods presented the best results.

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.

Although the pre-processing techniques are useful to obtain best images, in the other hand, they can generate those irregularities

CONCLUSION

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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