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Hough Transform Use in Image Processing of Microscopic Alloy Images

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Abstract: Presented paper presents principle of Hough transform on fundamental geometric forms and algorithm of its application. Fundamental geometric forms are used to explain core of this method. These statements are expanded on more complex simulated image and critical aspects of using Hough transform are discussed. Tested methods were applied on microscopic images of Al Alloy which were treated by conditions of Vickers indentation test.

1. INTRODUCTION

Field of Hough transform use interferes in many branches of practical applications. Line and shape detection is the very essence of detection of particles in cryo-electron microscopy images (Zhu et al. 2001, Zhu et al. 2003) for example. Aerial images are utilized for semi-automatic and automatic detection of rectangular structures, such as vehicles (Zhao et al. 2001) and buildings (Jaynes et al. 2003).
Most reported shape detection techniques are based on edge and line primitives. Some of these techniques are briefly described in next paragraphs.
Lagunovsky and Ablameyko (1999) based detection algorithm on lines. Lines are extracted first and these segments are grouped in straight lines in the next step. The length and orientation of these straight lines are compared and used to detect quadratangles that are futher approximated by rectangles.
Zhu et al. (2002) used the rectangular Hough transform (RHT) approach to detect rectangular particles in cryo-electron microscopy images. If the sides of rectangle are known, the RHT uses a 2D accumulator array to detect the center and orientation of rectangle. This method produced good results but known rectagle dimensions are required.

In this paper, we explore behaviour of Hough Transform (Duda et al. 1972) and its application to microscopic images of alloy images treated by Vickers indentation test (ČSN ISO 6507-1 1999).

The remainder of this paper is structured as follows. In the next Section, the Hough transform is briefly explaned. In Section 3, an influence of an edge detection on the Hough Transform is described. Section 4 analyse smoothing effects on the Hough Transform and its application to microscopic images is presented in Section 5. Results are concluded in Section 6.

2. HOUGH TRANSFORM

Hough Transform (HT) is processing method designed for line detection in image. Basic principle of HT is finding points which are common to one bisector. Polar coordinates are used for expressing this line. Usage of this method can be expanded to detection of fundamental geometric shapes, like square, rectangle or circle.
Very important is observing a good quality binary image which only can be treated by HT to gain equations of lines in image. This goal requires an application of edge detection methods as necessary pre-processing methods. Image filtering should be considered, as well.

Lines in an image can be represented as a subset of points. By finding bisector parameters from every pair of points, resulting lines can be gained. Because of computational demands of this problem, Hough proposed an alternative method. The very essence of this approach is a conversion of parameters to polar coordinates.
Consider an image with point (x, y). Through this point can be constructed infinity amount of bisectors with general equation (1) where a is a slope and b is a bisector intersection with y-axis. Both of these parameters go toward infinity if the line becomes more vertical. Conversion of this system into polar coordinates solves this problem efficiently. A presented process converts a and b parameters to parameter ρ which represents a distance of bisector from origin and parameter θ which express an angle of bisector with x-axis.

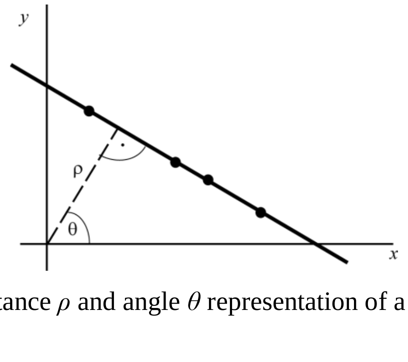

Fig. 1 Distance ρ and angle θ representation of a bisector

According to Fig.1, Eq. (1) can be expressed like Eq. (2).

$$y = ax + b \tag{1}$$

$$y = -\frac{\cos\theta}{\sin\theta}x + \frac{\rho}{\sin\theta} \tag{2}$$

$$\rho = x\cos\theta + y\sin\theta \tag{3}$$

By rearranging of Eq. (2), final Eq. (3) is gained. In contrast of *a* and *b* parameters, the parameter θ has finite domain of definition, $\theta \in$ <0, π>. Because we handle with image, parameter ρ has also finite domain of definition, $\rho \in$ <0, *D*> where *D* is diagonal of the image. The field of ρ and θ parameters is called Hough space.

2.1 Hough Transform of Point

Consider binary image with several white pixels (Fig. 2). This image was treated by Hough transform algorithm, so its Hough space was gained (Fig. 3).

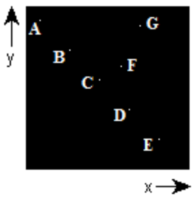

Fig. 2 Test points image

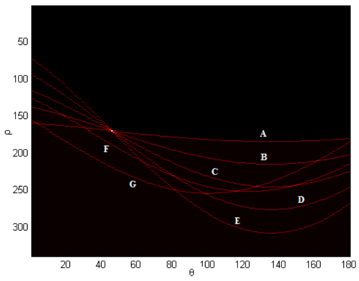

Fig. 3 Hough space of test points image (Fig. 2)

Set of testing point is presented in Fig. 2. It is obvious that points A, B, C, D, E make line and points F and G are out of this line. Hough space of this image (see Fig. 2) is shown in Fig. 3. Curves A – E intersects in one point which represents ρ and θ parameters of Eq. (3). Hough space gives information that points A – E lay on line with same equation, so they lay on same line.

Other intersections are present in this Hough space. It corresponds to other lines which are created by points [A, F], [B, F], [A, G], [B, G] and so on.

2.2 Hough Transform of Circle

Although HT detects just lines, circles in the image can be simply detected, as well. Consider binary image of circle. There are no lines to detect, so in Hough space no intersections are expected (Fig. 4). This property is typical for circle and can be used for its detection.

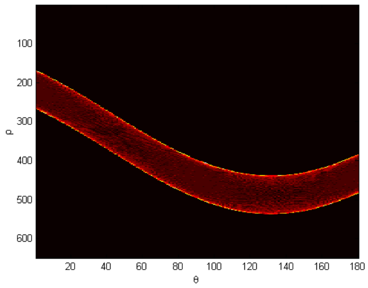

Fig. 4 Hough space of test circle image

2.3 Hough Transform of Square

HT of square also gives typical result. Square is composed from four line segments and four their intersections which lay on escribed circle. So Hough space (Fig. 5) looks like combination of point case and circle case.

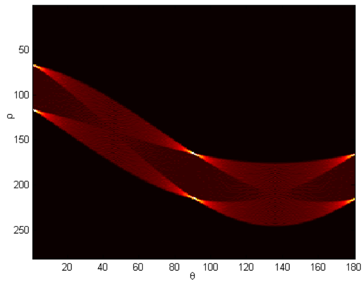

Fig. 5 Hough space of test square image

Curves intersections represent four cusps of square and curves are HT result of side points (Fig.5). Global shape of Hough space curves demonstrate mentioned scripted circle. Similar result can be gained for HT of various tetragons.

3. INFLUENCE OF EDGE DETECTION ON HOUGH TRANSFORM

For processing of real images a proper pre-processing algorithm should be applied. Input data must be converted into intensity image. In the next step edges are detected and at first resulting image will be treated by selected threshold method to gain binary image. Now, HT can be applied.

It is obvious, that edge detection is a critical parameter for successful line detection. Variuos edge detectors can be used - both gradient methods and detection algorithms. Prewitt's and Laplacian of Gaussian (LoG) methods were selected for representation gradient method group and Canny's detector was chosen from the second group.

These methods were applied on simulated testing image (Fig. 6) and a quality of edge and line detection was observed.

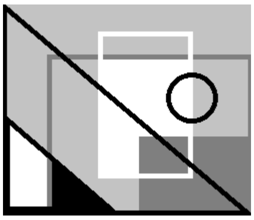

Fig. 6 Simulated image for observing of edge and line detection quality

Result of gradient method group edge detection is shown in Figs. 7, 8, 9 and line detection by HT is presented in Figs. 10, 11, 12.

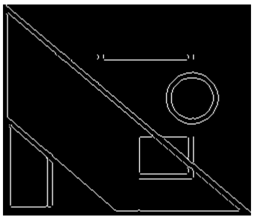

Fig. 7 Prewitt's edge detection of simulated image (Fig. 6)

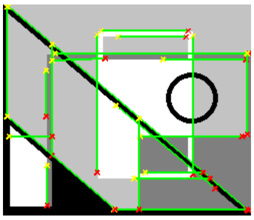

Fig. 10 Line detection of Prewitt's edge detection (Fig. 7)

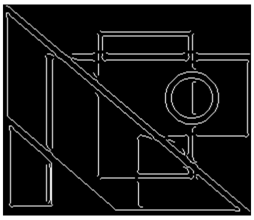

Fig. 8 LoG edge detection of simulated image (Fig. 6)

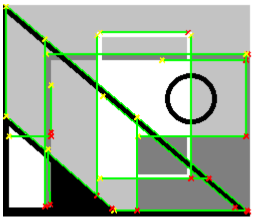

Fig. 11 Line detection of LoG edge detection (Fig. 8)

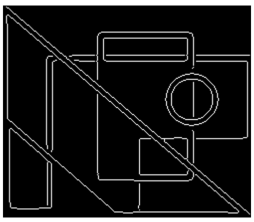

Fig. 9 LoG edge detection of simulated image (Fig. 6)

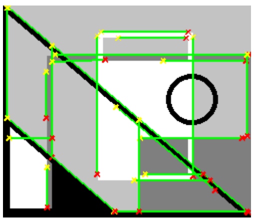

Fig. 12 Line detection of LoG edge detection (Fig. 9)

Presented binary images of edges in simulated image proved that Canny's edge detection algorithm is the best way how to process these data. LoG method was successful, as well, but there are some imperfections in detection of intersections. Prewitt's detector wasn't successful because it didn't recognized less intensive edges. Circle in simulated image wasn't pointed in any images in Figs. 10 - 12. This event has simply interpretation. In used HT algorithm, just lines were detected. For detection of circle, interpretation of Hough space data should be changed. Hough space of Canny edge detector image is shown in Fig. 13, for example.

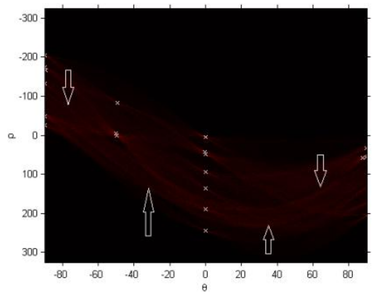

Fig. 13 Hough Space of Canny Edge Detector Image with Marked Feature Typical for Circle

4. SMOOTHING EFFECTS INFLUENCE ON LINE DETECTION QUALITY

In this part, influence of smooth image will be presented. Simulated image (Fig. 6) was smoothed by averaging filter of various sizes and effects on quality of line detection were observed. For edge detection, the most successful Canny's algorithm was used. Results of edge detection in smoothed images are presented in Figs. 14 - 16.

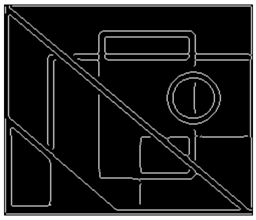

Fig. 14 Edge detection of 5x5 smoothed image

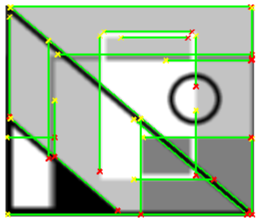

Fig. 17 Line detection of 5x5 smoothed image

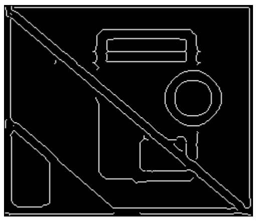

Fig. 15 Edge dection of 10x10 smoothed image

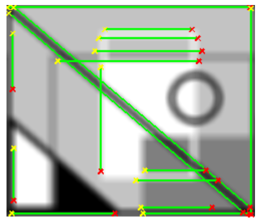

Fig. 18 Line detection of 10x10 smoothed image

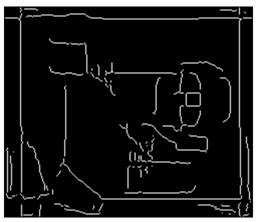

Fig. 16 Edge detection of 30x30 smoothed image

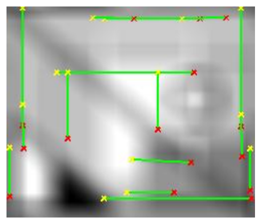

Fig. 19 Line detection of 30x30 smoothed image

Hough Transform was applied to pre-processed images and detected lines are shown in Figs. 17 - 19. These results show that smoothing hasn't direct influence on quality of line detection. Image smoothed by 5x5 averaging filter gave almost the same result as unsmoothed image (Fig. 17). Line detection of 10x10 smoothed image was less successful but almost all edges in Fig. 15 were detected. Smoothing by 30x30 averaging filter failed at line detection but the most of detected edges was detected as in former case. This result demonstrates that a smoothing has no direct effect on line detection but defects edge detection, only.

5. HOUGH TRANSFORM APPLICATION ON MICROSCOPIC ALLOY IMAGES

The final part of presented paper is focused on the application of HT on microscopic images of Al alloy. These images were taken by a scanning electron microscope and display new Al alloy treated by conditions of Vickers indentation test (ČSN ISO 6507-1).
This standardized method is based on an alloy sample treatment by diamond tetragonal pyramid (top angle $\alpha = 136°$) with a known load F to gain standardized puncture. The area of incurred puncture is inverse proportional to an induration of examined alloy. The puncture area is gained by measuring diagonals d_1 and d_2. Vickers induration HV is defined by Eq. (4)

$$HV = \frac{2F}{g}\sin\left(\frac{\alpha}{2}\right)\frac{1}{d^2} = 0.189F\,\frac{1}{d_1 d_2} \qquad (4)$$

where g is a gravity acceleration.

The goal of presented project is automatic evaluation of this puncture and measurement its diagonals by no human affection with help of HT.
Al alloy image was selected for development of processing algorithm. Proper pre-processing was necessary first step. A histogram of input image was evaluated then it was equalized and an image intensity was adjusted. Mathematic morphology methods were applied later. Modified image was dilated by a rectangle structural element, first, and then eroded by a similar element. Edge detection was applied on the resulting image. The last step was line detection by HT (see Figs. 20 – 23).
Troublesome effects of alloy sample preparation (long scratches in Fig. 20) were taken out by morphological methods, so only edges belonging to puncture were detected. Resulting image showed that lines in puncture image were detected successfully.

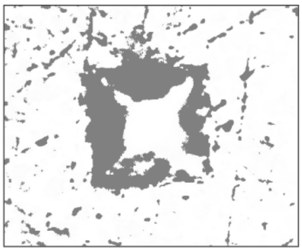

Fig. 20 Al alloy image after histogram equalization and intensity adjustment

Fig. 21 Al alloy image after mathematical morphology

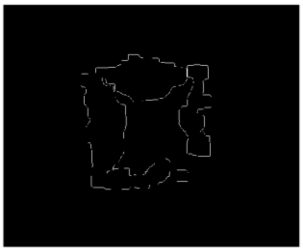

Fig. 22 Edge detection of Al alloy image

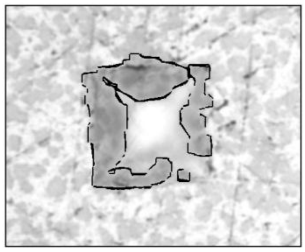

Fig. 23 Line detection of Al alloy image

Presented algorithm was applied on other images of Vickers induration test. A selected result of the algorithm examination is displayed at Fig. 24.

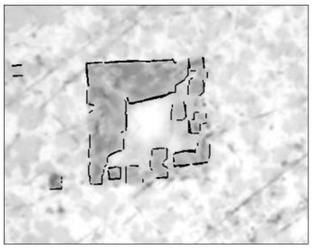

Fig. 24 Line detection of sample image No. 23

6. RESULTS AND CONCLUSION

Presented results showed that Hough transform is powerful tool for detection of shapes in the image. Testing image application proposed robustness from smoothing images, so it was proved that weak step of HT algorithm is efficiency of edge detection.
Algorithm of HT use on Al alloy images was developed and verified on selected set of alloy images. It is necessary to pre-processed input images to avoid influence of troublesome effects. After this, edge and line detection can be implemented successfully.

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