NEW ALGORITHM FOR KIKUCHI LINES DETECTION IN ELECTRON MICROSCOPY IMAGES

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ABSTRACT

In material sciences crystals' features are deduced from Kikuchi bands (lines) that are present in electron microscopy images. In the paper a new algorithm for detection of the Kikuchi bands is proposed and its subsequent stages are described. A performance test of the algorithm is carried out.

1. INTRODUCTION

Possibility of reproducible manufacturing of crystal materials with desired physical properties is one of the most important problems in material engineering. The crystal material properties are mainly determined by size and spatial orientation of crystal domains that in turn can be deduced (calculated) from the position of pairs of so-called Kikuchi bands (lines) existing in electron microscopy images (see figure 1). The determination of size and orientation of domains is possible only after examining several thousands of images, therefore the problem of automatic detection of Kikuchi bands (lines) is of high importance.

The Hough transform [1] is one of the most popular and computationally efficient numerical tools which is typically exploited for line detection. Its usage for Kikuchi lines localization has been already reported in literature [2, 3, 4].

The aim of this paper is to propose a new algorithm for accurate Kikuchi lines detection. The method utilizes multi stage preprocessing of the source image. It performs such image operations as: de-noising, directional filtration with proposed masks, binarization and enhancement via sequence of morphological operations. Furthermore, the method makes use of some modifications applied to the classical Hough transform. Its detail description, performance and properties will be discussed in the following sections. The proposed method consists of two stages: initial image preprocessing and modified Hough transform.

2. INITIAL IMAGE PRE-PROCESSING

2.1. Denoising

Source images are usually corrupted by noise which would make further processing more complex computationally and less reliable. Therefore initial denoising step is performed first using median filter with 2-pixel wide window.

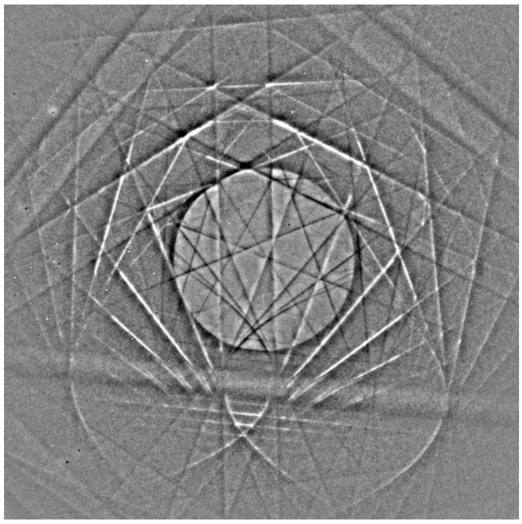

Fig 1. An example of a source image

2.2. Directional filtering

Some Kikuchi lines are hard to detect without any enhancement. Therefore, in order to increase the probability of detection of barely visible lines, the denoised image is filtered twice with a mask oriented at each of four orientations: vertical, horizontal and at the angles of 45 and 135 degrees. The filtration if performed as a 2D convolution.

The horizontal mask is obtained from the vertical mask by rotating it 90 degrees counter-clockwise. The mask oriented at the angle of 135 degrees is obtained by rotating the vertical mask 135 degrees counter-clockwise.

As a result four filtered images are obtained (see fig. 2) that are processed separately later. By the filtering two goals are obtained simultaneously: 1) weak lines are significantly amplified and therefore they are more easily detected, 2) lines perpendicular to the relevant mask orientation are filtered out which leads to reducing the rate of false lines detections (false "positives").

Table 1 Vertical mask

1	0	0	0	0	0	**-1**
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1	0	0	0	0	0	**-1**
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1	0	0	0	0	0	**-1**

Table 2 Mask oriented at the angle of 45 degrees

0	0	0	0	**-1**	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	**-1**	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	**1**
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	**1**	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	**1**	0	0	0	0

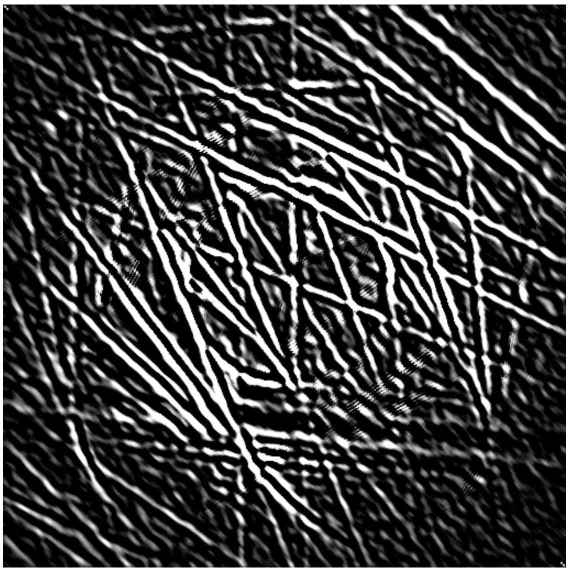

Fig. 2. The source image after directional filtering.

2.2. Segmentation (binarization)

In this step each filtered image is segmented into *background* and *objects* (*lines*). A bi-level global thresholding method with a threshold selection based on Renyi's entropy measure [5] is applied. The method makes use of the maximum entropy sum method and the entropic correlation method. Each pixel that has a grey value below or equal to the threshold is assigned to the background, and the pixel with a grey value above the threshold is assigned to the object.

2.2. Binary image enhancement

At present a sequence of the following morphology operations is performed in order to make the binary images more suitable for further analysis.

a) Dilatation – filling some lines' gaps that may appear after binarization.
b) Thinning the binary image – the method described in [6] is applied.
c) Removing isolated pixels (1's surrounded by 0's) – these pixels carry almost no information about lines.
d) Removing all pixels that have more than 2 non-zero neighbours – this is done in order to separate connected objects (lines).
e) Selecting the best-distinguished pixels that offer most accurate line parameter estimation. For line fitting, the end points of a line are the best-distinguished pixels. The end points are found by checking the connectivity around a pixel. If a pixel connects to only one other pixel then it is an end point of a line. As a result we have two end points for each line in the image: (x_1,y_1) and (x_2,y_2). Then they are used to estimation of line orientation according to the following formula:

$$\varphi_k = \arctan\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \quad when\; x_2 \neq x_1$$
$$\varphi_k = 90° \quad when\; x_2 = x_1$$

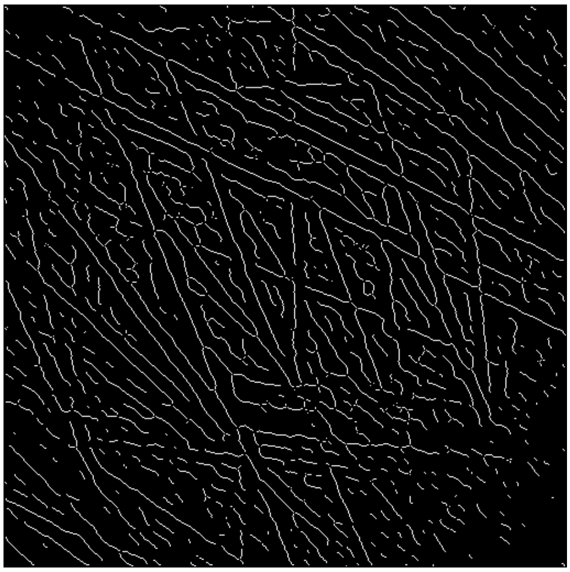

Fig. 3. The image after thinning step

3. MODIFIED HOUGH TRANSFORM

After preprocessing all four images, each of them is next analysed using a modified Hough transform (MHT). The transform operates on thinned binary images (one of them is shown in figure 4). Proposed modification relies on taking into account previously extracted information concerning the estimated lines orientations in the image (φ_k angles). For each possible line orientation (θ) passing through each pixel, the corresponding value of accumulator cell (Acc) is increased by the value $f(|\theta-\varphi_k|)$. The angle $\theta-\varphi_k$ is the one between the current possible line orientation and the estimated k-th line orientation. Value added to the relevant accumulator cell depends on a *voting* function $f(|\theta-\varphi_k|)$. We have examined three possible outlines of this function.

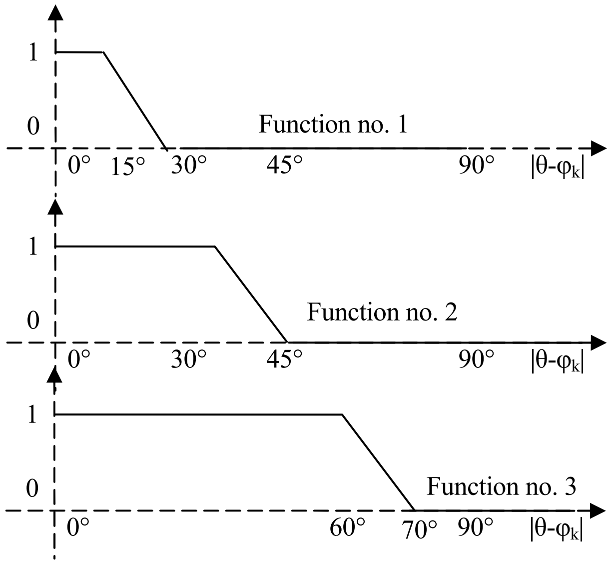

Fig. 4. Outlines of three examined voting functions

The average number of correctly and incorrectly found lines per image was calculated for each of examined functions. The results are show in table 3.

Table 3. Obtained results.

function	Correctly found lines	Incorrectly found lines
Function 1	16	3
Function 2	24	6
Function 3	25	10

Finally, the function no. 2 was chosen because it yields the best results.

In consequence, accumulator cells corresponding to the parallel orientations (the most probable line orientations) to the estimated orientation, are increased by 1 and cells corresponding to line perpendicular orientations (the least probable line orientations) to the estimated orientation are not changed. The procedure of updating the accumulator with values depending on current possible line orientation and estimated orientation, leads to significant reduction of information noise present in parameter space. As the result, the probability of false line detections is reduced. The proposed modified Hough transform algorithm is presented in table 4. In turn, an exemplary normalized MHT image is shown in figure 5.

Each of four MHTs is thresholded with an empirically found threshold. In order to determine the best threshold value, we have examined the number of correctly found lines and the number of false positives depending on its choice, and determined the optimal one. On the basis of obtained results (see figure 6) the threshold value has been set to 0.45. The higher threshold results in smaller number of detected lines whereas the lower one gives more false positives without any increase in the number of correct lines.

All accumulator cells that have values above the threshold are retained for further processing. The parameters (r,θ) corresponding to the retained cells describe location of detected Kikuchi lines.

Table 4. The algorithm of MHT

```
Set Acc(θi,ρi)=0 – all accumulator cells are set to 0
 for each non-zero binary image pixel
            {
            for θ=φk-45° to φk+45°
                        {
                        ρ=x•cos(θ)+y•sin(θ)
                        Acc(θ,ρ)=Acc(θ,ρ)+f(|θ-φk|)
                        }
            }
 (x,y) – coordinates of a non-zero image pixel
 φk – estimated orientation of a line passing through
        relevant pixel (x,y)
```

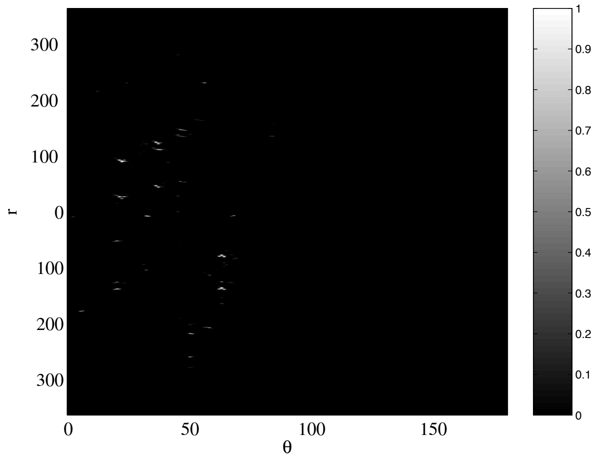

Fig. 5. An exemplary normalized MHT image.

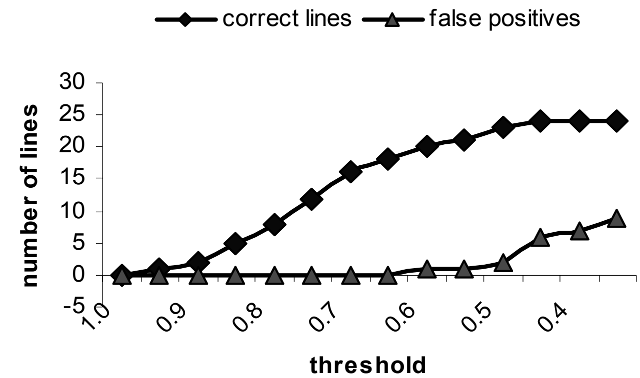

Fig. 6. Number of correctly and incorrectly (false positives) found lines depending on the threshold value

In order to decrease the probability of non-existing lines detection ("false positives") an additional verification step is performed. If the value of accumulator cell is in range from 0.45 to 0.7 then existence of corresponding line (r,θ) is additionally checked in the binary image directly (lines with accumulator values higher than 0.7 are not verified because they can not be "false"). A special mask is created representing a straight line passing through points specified by the parameters (r,θ). For the pixels lying along the mask, the following parameter is defined:

$$p = \left(\max\left\{ \sum_{i=1}^{N} Y(i) \right\} \right) \Big/ N$$

where:

$$Y(i) = \begin{cases} 1 & \text{if the } i\text{-}th \text{ pixel on the line is equal to 1} \\ -1 & \text{if the } i\text{-}th \text{ pixel on the line is equal to 0} \end{cases}$$

and N is the length of a mask. The value of p varies from -1 to 1. It is close to -1 when pixels along the mask make up a long sequence of pixels of value 0 and close to 1 when the line contains a long sequence of pixels of value 1. This is the case when the mask covers the Kikuchi line. Otherwise the value of p is near 0 or less than 0. In consequence, when the p value is above the empirically chosen threshold then a line specified by (r,θ) is added to the output list by the algorithm.

The threshold value for the p parameter has been determined experimentally. For different thresholds, an average number of correctly and incorrectly verified lines per image has been calculated. Obtained results are presented in figure 7. On their base the threshold has been set to 0.35. This value ensures maximum number of correctly verified lines and, the same time, the minimum number of incorrectly recognized ones.

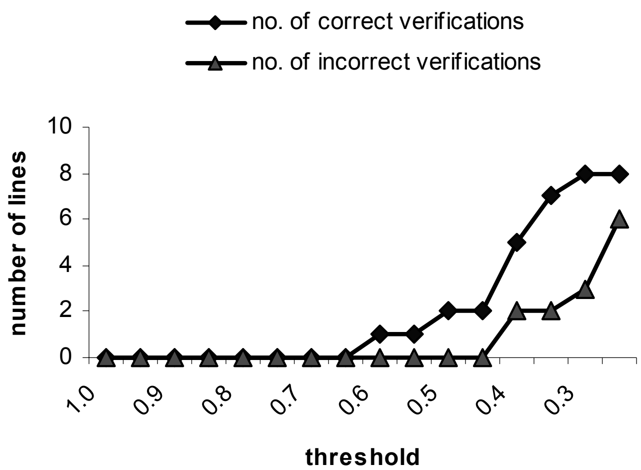

Fig. 7. Average number of correctly and incorrectly verified lines per image as a function of the parameter p value.

Finding pairs of parallel lines in the list represents the final step of the proposed Kikuchi lines detection algorithm.

4. RESULTS

The proposed algorithm has been implemented in MATALB language and tested using 30 images having 312 Kikuchi line pairs. Obtained results have been compared with the ones achieved from two reference algorithms. Algorithm 1, implemented and tested by authors, has been based on the standard Hough transform (SHT) and equipped with no advanced pre-processing and no additional results verification. Algorithm 2, also based on the SHT, is in everyday use in the Institute of Metallurgy and Materials Science of the Polish Academy of Sciences, Cracow, Poland. The total number of correctly detected pairs of Kikuchi lines and incorrectly found pairs have been measured. Obtained results are presented in table 5. The proposed algorithm is significantly better than the algorithm 2 that is typically utilized by material science professionals for routine measurements.

Future research will be focused on additional reduction of computational and implementation complexity of the elaborated algorithm.

Table 5 Results comparison

Method	Correctly found pairs of lines	Incorrectly found pairs of lines
Proposed	261 (**83.7%**)	2 (**0.6%**)
Algorithm 1	212 (67.9%)	28 (9.0%)
Algorithm 2	224 (**71.8%**)	36 (**11.5%**)

REFERENCES

[1] I. Pitas: *Digital Image Processing Algorithms*, Prentice Hall, Hertfordshire 1993.

[2] K. Lassen, N.C., Jensen, D. J., and K. Conradson: “Image processing procedures for analysis of Electron back Scattering Patterns.” Scanning Microscopy vol. 6, pp. 115-121, 1992.

[3] K. Lassem: “Automatic high-precision measurements of the location and width of Kikuchi bands in electron backscatter diffraction patterns”, Journal of Microscopy, vol. 190, pt.3, pp.375-91, Blackwell Science for R. Microsc. Soc, UK, June 1998.

[4] S. Krämer, J. Mayer: “Using the Hough transform for HOLZ line identification in Convergent Beam Electron Diffraction.”, Journal of Microscopy. vol. 194, Issue 1, pp. 2-11, 1999.

[5] P. Sahho, C. Wilkins, J. Yeager, “Threshold selection using Renyi’s entropy”, Pattern Recognition, Vol. 30, No. 1, pp. 71-84, Pattern Recognition Society, 1997.

[6] L. Lam, Seong-Whan Lee, C. Y. Wuen, “Thinning Methodologies - A Comprehensive Survey”, IEEE Trans. on PAMI, vol. 14, no. 9, pp. 869-885, 1992.

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