# Contouring of microcapillary images based on sharpening to one pixel of boundary curves

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## ABSTRACT

The paper presents a new sharpening method that can be applied for the low-contrast medical images as well as general edge detection. The method provides more reliable diagnosis of the vascular system based on image processing. The new contouring method was compared with Sobel, low-frequency filtration and Canny edge detection methods on the example images with micro-capillaries.

**Keywords:** medical images, edge detection, image sharpening

## 1. INTRODUCTION

Capillaroscopy applies the geometrical dimensions of capillaries. They are used as input data for hydrodynamic calculation of the secondary parameters of the vascular system (Fig. 1) and are related to:
– the diameter of the arterial section in the range of 11...21μm;
– diameter of the venous section in the range of 16...30μm;
– diameter of the transition section in the range of 17...32μm;
– distances between capillary and venous sections;
– length of the capillary;
– perivascular space in the range of 118...133μm;
– perivascular segment;
– density of the capillary network in the range of 4...7%.

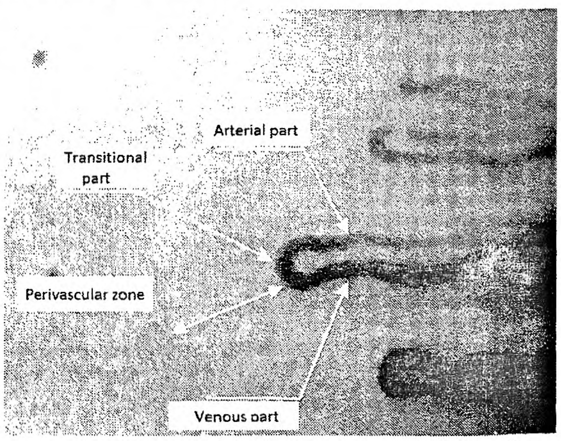


Figure1. Microcapillaries image with different zones marked.

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The problem of visualization of objects in low contrast images consists in defining clear boundaries of the objects for further automated calculation of their parameters and to facilitate visual perceptions by humans.

There are specific required at the preprocessing stage of the vascular system images: the edge lines must be continuous, the images must not contain false edge lines, the width of the edge lines should be of one pixel width, the edge line must be graduated by brightness to separate useful lines from noise component. Because of the specific nature of acquiring medical images of viscera they are rather blurred[1]. It complicates edge detection process. Known methods of edge detection based on convolution of the image with differential masks (like Sobel, Prewitt or Roberts methods[2]) give wide blurred edge line for such images. Known Canny method[3] gives a thin edge line of 1 pixel width, but such a line has many gaps and false elements. The method of low-contrast filtering[3] gives a thin line of one pixel width but does not provide the possibility to differentiate brightness of the lines depending on the brightness differential making difficult separation of significant and insignificant elements.

## 2. METHOD REALIZATION AND STUDY

Following the mentioned circumstances, new methods of sharpening to maximum slope of the boundary curve and edge detection has been proposed, that are based on common points of initial image and the image with increased sharpness. To form a mask of weight coefficients, the following indicators are introduced:

$$k_{wh} = 1 \quad \text{if} \quad I_{ij} \geq \frac{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} (I_{wh})}{n^2}; \tag{1}$$

$$k_{wh} = 0 \quad \text{if} \quad I_{ij} < \frac{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} (I_{wh})}{n^2}, \tag{2}$$

where $n$ – size of a mask; $I_{ij}$ – input value of current pixel intensity.

When moving the mask on the image, in the place of difference the indicator will change its value from 0 to 1 for the leading front of the boundary curve slope or vice versa from 1 to 0 for the back front.

Knowing the place where indicator changes its status, the intensity difference should be intensified for further contour detection. Mathematically intensification means that the pixels neighboring the difference of lower intensity than the current pixel should be even lowered, and those of higher intensity should be increased. It is achieved by comparing intensity of the central and adjacent pixels. At that the mask of weighting coefficients $z_{wh}$ is formed as:

$$z_{wh} = 1 \quad \text{if} \quad I_{iwh} \geq I_{ij}; \tag{3}$$

$$z_{wh} = 0 \quad \text{if} \quad I_{iwh} < I_{ij}, \tag{4}$$

where $I_{wh}$ – value of pixels intensities in a vicinity of the central pixel $I_{ij}$. Thus, the weights for each captured pixel are calculated by comparing the intensity of the central pixel with the intensity of the average in the window and with each pixel in the window separately.

Therefore, the process of sharpening to a maximum slope at boundary curve involves the following steps:
1) specifying the $n \times n$ mask depending on the width of the intensity drops;
2) calculating the average intensity value of pixels in a moving window;
3) comparing the intensity of the central pixel with the average value of the window;
4) comparing intensity values of each pixel in the window with the intensity value of the central pixel in the window;
5) forming the mask of weight coefficients;
6) forming a new mask for the next pixel with weights on the above algorithm.

In general, the mathematical model of sharpening can be described by equations[5] (5):

$$\begin{cases} I'_{ij} = \dfrac{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} \left( I_{wh} \cdot \left( \overline{k_{wh} \oplus z_{wh}} \right) \right)}{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} \left( \overline{k_{wh} \oplus z_{wh}} \right)}; \\ k_{wh} = 1 \quad \text{if} \quad I_{ij} \geq \dfrac{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} \left( I_{wh} \right)}{n^2}; \\ k_{wh} = 0 \quad \text{if} \quad I_{ij} < \dfrac{\sum_{w=i-(n-1)/2}^{i+(n-1)/2} \sum_{h=i-(n-1)/2}^{j+(n-1)/2} \left( I_{wh} \right)}{n^2}; \\ \qquad z_{wh} = 1 \quad \text{if} \quad I_{iwh} \geq I_{ij}; \\ \qquad z_{wh} = 0 \quad \text{if} \quad I_{iwh} < I_{ij}, \end{cases} \tag{5}$$

where $n$ – mask size; $I_{ij}$ – input value of current pixel intensity; $I'_{ij}$ – output value of current pixel intensity.

To confirm the effectiveness of the developed method, a number of studies using the synthesized image model with sharp drops in intensity of one pixel was performed. This image was superimposed by additive Gaussian noise of 150–200% intensity and blurred several times. In the resulting image the intensity difference is about 17...19 pixels. The noisy and blurred image was processed by sharpening filters, that were implemented in Image in Depth, Photoshop, CxImage, Matlab (Laplacian mask) and the proposed sharpening method with a maximum slope boundary curve. The resulting image was compared with the input image according to the following criteria: PSNR, mean square error and normalized mean square error and criteria of normalized correlation that are presented in Table 1.

Table 1. Values of comparison criteria

| Methods \ Criteria | PSNR | MSE | NMSE | NK |
|---|---|---|---|---|
| Image in Depth | 15.3 | 1214 | 0.0117 | 1.0032 |
| Photoshop | 27.4 | 1062 | 0.006 | 1.0047 |
| CxImage | 31.2 | 315 | 0.0032 | 1.0009 |
| Laplacian filter | 33.2 | 252 | 0.0014 | 1.0054 |
| Maximum slope sharpening method | 35.7 | 220 | 0.0012 | 1.0072 |

The research results show that PSNR and NK criteria for the proposed method are higher than others. And MSE and NMSE are lower, indicating a more accurate image reproduction with clear differences of intensity using the proposed method.

The high accuracy of reproduction is due to the fact that the original image had sharp drops in intensity of one pixel and it returned to its original view with some slight distortion after sharpening. And the known sharpening methods have not reduced the intensity difference, but only increased its value.

### 2.1 Contouring method

After sharpening by the proposed method, image edge detection can be made by the known methods. However, still some problems occur. The edge detection methods, giving the contour lines of equal brightness (such as Canny method or low frequency filtration method), make it impossible to detect the significant and insignificant elements of the image. Masks approaches using convolution operations for each individual pixel give multicolor edge in the inhomogeneous background that causes problems for edge line binarization. An edge detection method is proposed basing on finding intersection points of boundary curves of the input image and the image after proposed sharpening[6]. An array of common edge points can be obtained as a result of elementwise processing, as shown in (6).

$$
I_c(m,n)=\begin{cases} I' \text{ while } (I_s(m-1,n)-I(m-1,n))\cdot(I_s(m,n)-I(m,n))<0 \\ \& \ (I_s(m,n)-I(m,n))<(I_s(m-1,n)-I(m-1,n)); \\ I' \text{ while } (I_s(m+1,n)-I(m+1,n))\cdot(I_s(m,n)-I(m,n))<0 \\ \& \ (I_s(m,n)-I(m,n))<(I_s(m+1,n)-I(m+1,n)); \\ I' \text{ while } (I_s(m,n-1)-I(m,n-1))\cdot(I_s(m,n)-I(m,n))<0 \\ \& \ (I_s(m,n)-I(m,n))<(I_s(m,n-1)-I(m,n-1)); \\ I' \text{ while } (I_s(m,n+1)-I(m,n+1))\cdot(I_s(m,n)-I(m,n))<0 \\ \& \ (I_s(m,n)-I(m,n))<(I_s(m,n+1)-I(m,n+1)); \\ 0 \quad \text{otherwise} \end{cases} \tag{6}
$$

where $I$ – intensity value in corresponding point of the input image; $I_S$ – intensity value in the corresponding point of the sharpened image; $I'$ – value of intensity gradient of the sharpened image in the corresponding points.

As a result, the edge of different brightness levels is formed. Using simple algorithm edge lines are brought to the same brightness and using the threshold techniques the required contours are outlined and the noise component are removed. In order to study the proposed edge detection method for low-contrast objects, the results of its work were compared with the results of known detectors on specially synthesized images. The quality and accuracy of the edges in the processed synthesized image were considered in the comparison. The best results are showed by the low-frequency filtering methods, Canny detector and the proposed method. Therefore, the additional study of edge lines quality was performed for more credible results. The criteria of Pratt and MSE of coordinate of the real in different parts of the image was used for Canny detector, low-frequency filtering method and the proposed method based on the common points of the boundary curve before and after sharpening. The results of researches are listed in Table. 2.

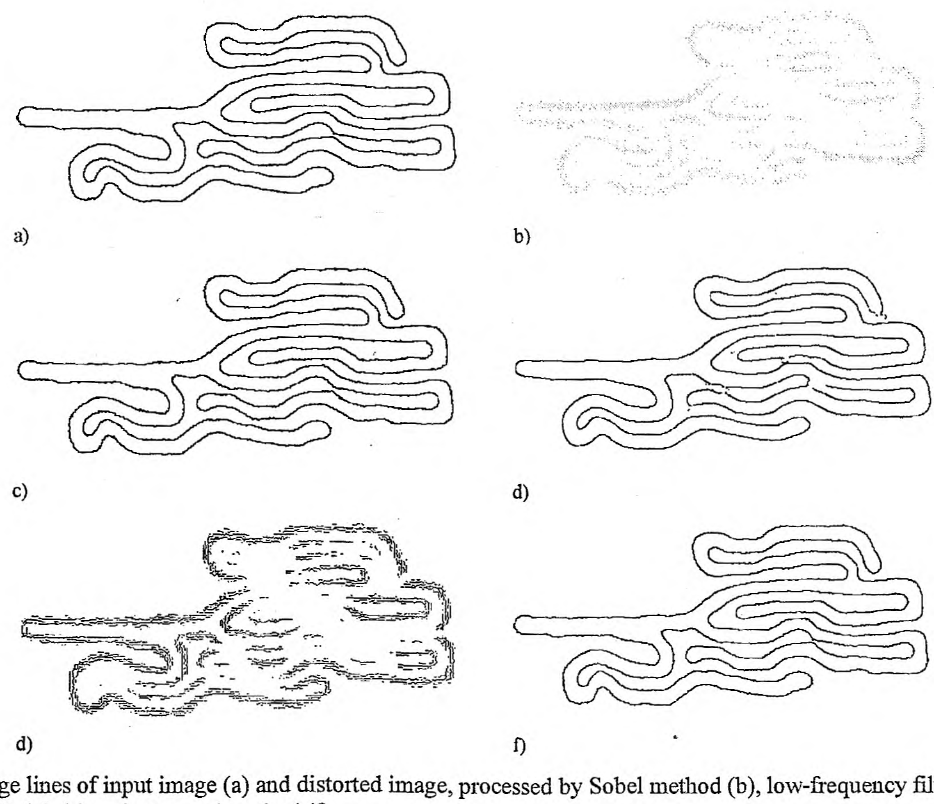


Figure 2. Edge lines of input image (a) and distorted image, processed by Sobel method (b), low-frequency filtration (c), Canny (d), Matlab (e) and proposed method (f).

Table 2. Value of Pratt criteria and MSE of coordinates on different parts of image for Canny detector, L/F filtering and the proposed method

| Part | Canny detector | | L/F filtering method | | Proposed method | | Notes |
|---|---|---|---|---|---|---|---|
| | MSE | Pratt | MSE | Pratt | MSE | Pratt | |
| 1 | 2.62 | 0.68 | 0.99 | 0.9 | 0.93 | 0.91 | Sharp edge |
| 2 | 3.6 | 0.44 | 2.1 | 0.79 | 1.9 | 0.82 | Gap (Canny) |
| 3 | 3.47 | 0.45 | 2 | 0.8 | 1.81 | 0.83 | Gap (Canny) |
| 4 | 2.24 | 0.80 | 2.22 | 0.81 | 2.21 | 0.81 | Part without distortions |
| 5 | 6.3 | 0.29 | 4 | 0.4 | 3.22 | 0.47 | Gap (Canny) |

The results (Table. 2) show that the efficiency of the edge detection by the proposed method is 2...2.5 times higher on the problem parts of the image and the same efficiency on the easy parts in comparison with Canny detector and 10...15% higher efficiency compared to the low-frequency filtering method.

Thus, visual analysis and appropriate numeric criteria confirmed higher quality of the edge lines obtained using the proposed method in comparison with the known methods (Fig. 3).

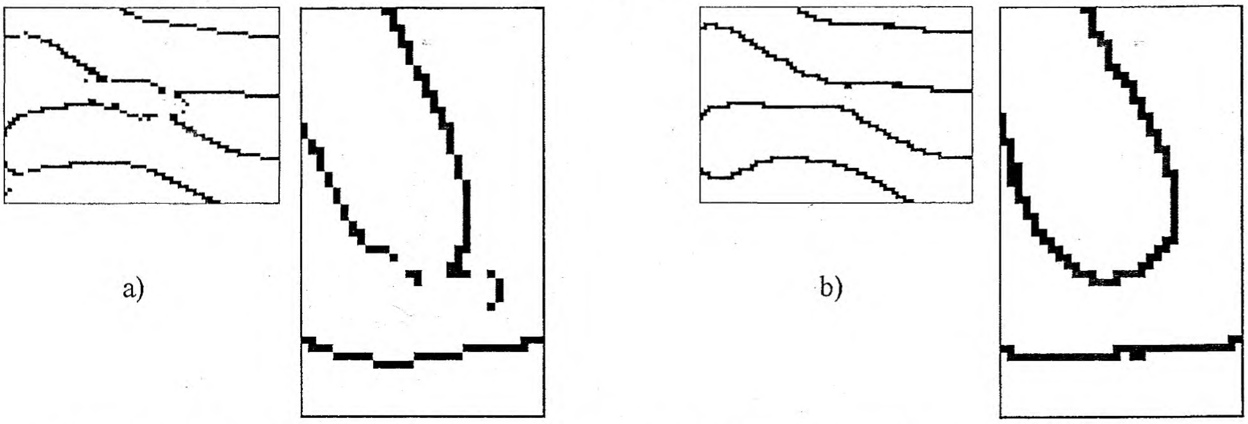



Figure 3. Enlarged parts of the edge lines obtained by the methods: a) Canny, b) proposed method.

## 3. APPLICATION OF THE PROPOSED METHODS

Since the input images of micro capillaries are low contrasted and blurred, then edge detection is performed on the basis of the developed methods. Fig. 4 shows studied image of micro capillary obtained by computer capillaroscope after noise reducing (pulse noise and additive – by linear filtering) and contrast improving using stretching of brightness histogram.

Analysis of the image indicates that the sharpness of the image is increased visually, but at the same time the high-frequency noise component also increased, the images became grainier. Such sharpening will insignificantly influence the reliability of edge detection in image. Fig. 6 shows a resulting microcapillary image after applying the method of sharpening to maximum slope of boundary curve. It has clearly seen differences in brightness. Fig. 7 shows waveforms of the boundary curves of the same line of the image processed by classic method of sharpening and the proposed one.

From these oscillograms, one can analyze the operation of the detectors. In case of sharpening in Photoshop, the intersection point is slightly shifted relative to the middle of the difference. And using the proposed sharpening method one can notice, that the boundary curves before and after sharpening intersect close to the middle of the deferential width. Besides, having such intersect the brightness of the edge line can be differentiated depending on the brightness differential.

So, after preliminary image processing that included pulse filtration and additive noise filtration, and improving contrast by using brightness histogram stretching, the next phase is performed. It includes sharpening to maximum slope of boundary curve and edge detection based on finding the intersection points of the boundary curves before and after sharpening[6,7].

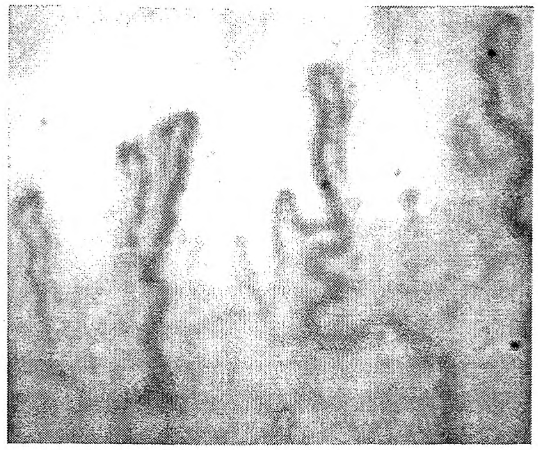


Figure 4. Image of microcapillary obtained by computer capillaroscope after noise reducing and contrast improving.

Fig. 5 shows the results of sharpening by known operator.

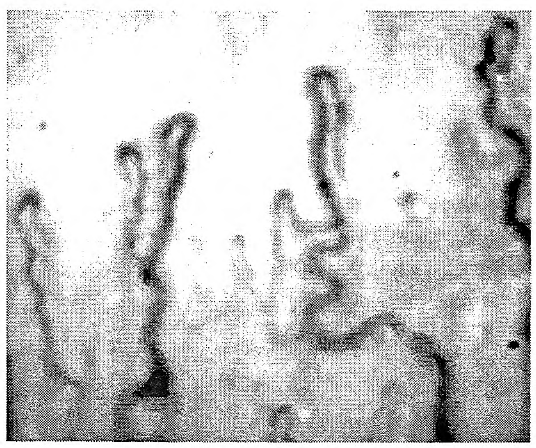


Figure 5. Results of microcapillary image sharpening by means of Photoshop.

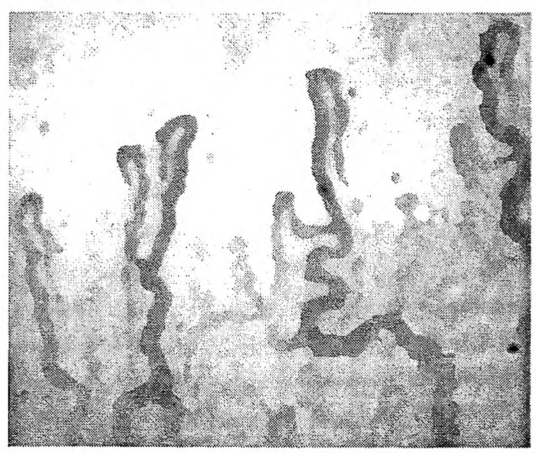


Figure 6. Resulting micro capillary image after processing by the method of sharpening to maximum slope of boundary curve.

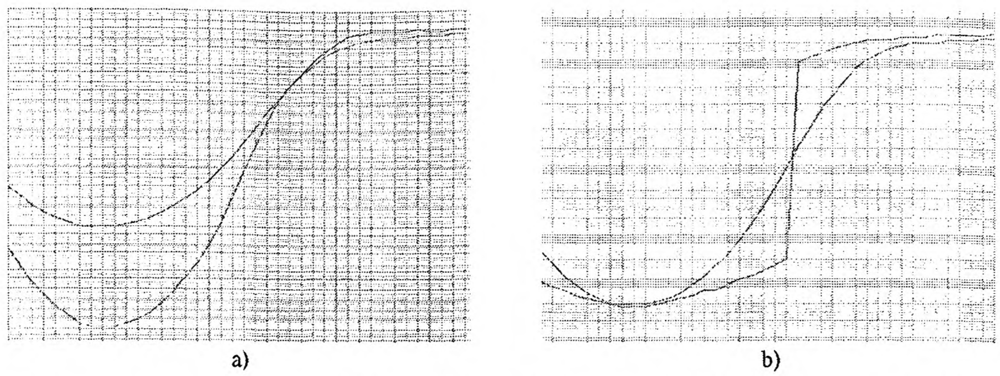


Figure 7. Waveforms of the boundary curves of the same line of the image processed by different methods of sharpening: a) Photoshop, b) sharpness method to maximum slope of the boundary curve.

### 3.1 Edge detection

The different approaches of edge lines detection of capillaries are further analyzed to select the optimal detector in terms of the problem of measuring its geometrical parameters.

*Operators based on gradient methods* have different window sizes, weights and methods of registration. In practice to calculate the discrete gradients, the operators with higher mask size are used to reduce sensitivity to noise. If low-contrast images are processed, it is difficult to get edges by these methods as gradient value and noise practically have the same value. Moreover, the edge line obtained by this method is fuzzy and blurred, though continuous. It prevents automatic detection of the vessel and the calculation of its geometrical parameters. Fig. 8 shows the result of edge detection of the micro-capillaries by Sobel method. To detect the geometrical parameters in such an image is practically impossible. Fig. 8 b shows the result of edge detection by the same method but after sharpening by the proposed method. Though the edge lines are thin but the image background is heterogeneous making difficult edge line binarization.

*Edge detection using Canny detector.* The advantage of the Canny detector is the ability to bypass the edge line around the object even if the level of brightness drops is low enough. This feature is achieved by selection of input and output values of the threshold gradient. Therefore, the lower the input threshold and the higher the output one, the more edge lines will give Canny detector.

Fig. 9. a shows the edge image detected by Canny detector. As it can be noticed in the capillary edge image, Canny detector defects appeared in the form of gaps, false contour lines and incorrect detection of Y-branches. Fig. 9, b shows a micro-capillaries edge image, that was detected using Canny detector after sharpening to maximum slope of the boundary curve.

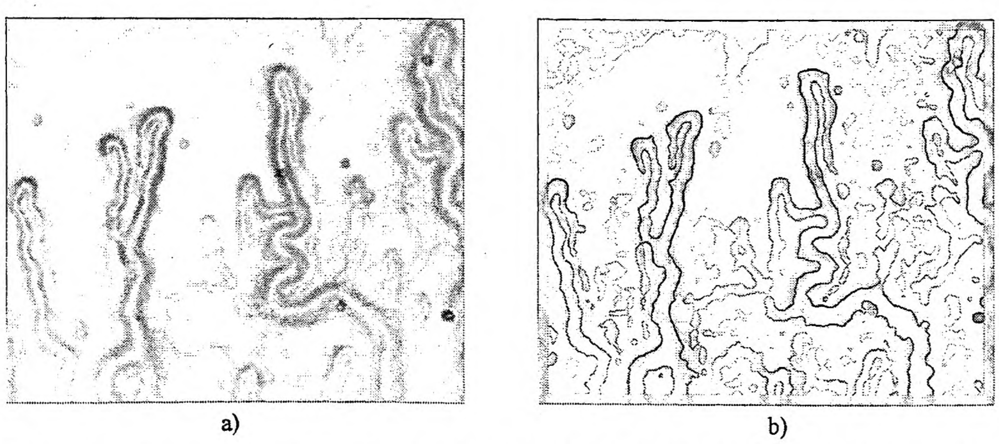


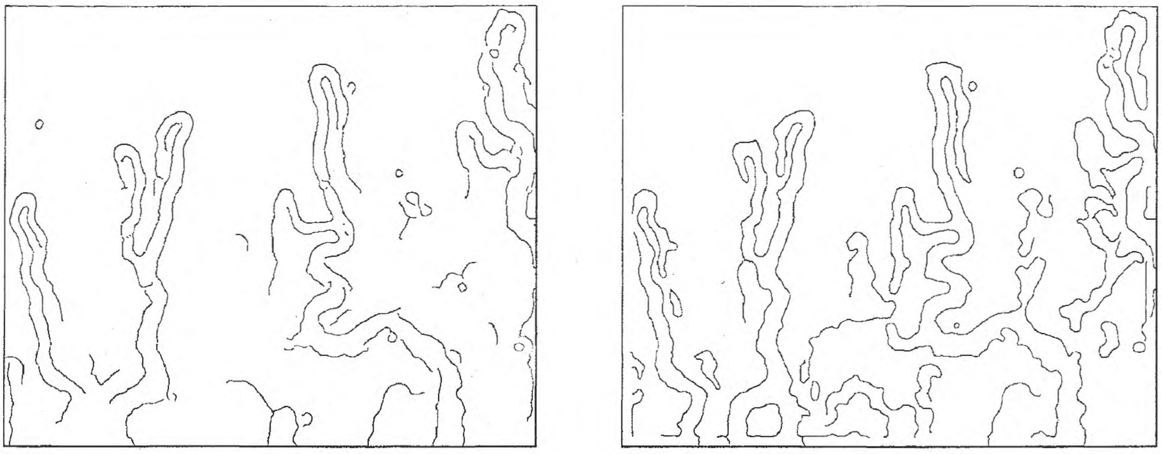
Figure 8. The resulting images of micro-capillary contours, obtained by Sobel method, before (a) and after (b) sharpening by proposed method.

Visual edge image analysis allows to evaluate its quality and leads to the following conclusions:

- edge line obtained after using sharpening by the proposed method have no breaks, unlike edge lines detected without using it;
- after using the proposed sharpening procedure, Canny detector provides much less false edge lines or double lines, but still detecting many additional lines, which are desirable to be deleted.

*Contouring by means of method based on finding intersection points of boundary curves of the initial image and the sharpened image* is an optimal decision for that case, because it has several advantages:

- simple to perform;
- thin contour line of one pixel width;
- continuity of the edge line;
- fewer obviously false edge lines;
- the possibility of differentiating the brightness of individual pixels of the edge lines to separate the "useful" lines from unnecessary;



a) b)

Figure 9. Resulting micro capillary edge image obtained by Canny detector, before (a) and after (b) sharpening by proposed method.

Fig. 10 shows microcapillary edge image obtained by the mentioned method. Visual observing gives an opportunity to make sure that edge lines are continuous and its width is one pixel. Beside that image contains a contour line as large as small capillaries. It is noticeable that the intensity of contour lines is not homogeneous and further work is to bring them to the same brightness.

*Removing of fake edge lines.* Removing fake edge lines is carried out in two stages. The first – by means of known methods each edge line, which had a different brightness at each point, is brought to one level of brightness (maximum in that line). Bringing to a homogenous brightness of each edge line is as follows. The background of the image is the same in each pixel, but the intensity of each edge pixel is different. If identifying the pixels with an intensity higher than the adjacent (not the background pixels), the neighboring pixel and all connected with it edge pixels are filled with its color.

Figure. 10. Resulting edge lines obtained by the method, based on finding intersection points of the boundary curves of the initial image and the sharpened image.

In the second stage by introducing a threshold, the lines of lower intensity are removed and of higher intensity are saved. Fig. 11 shows the result of the procedure after the first stage, whereas Fig. 12 shows the results after the second one.

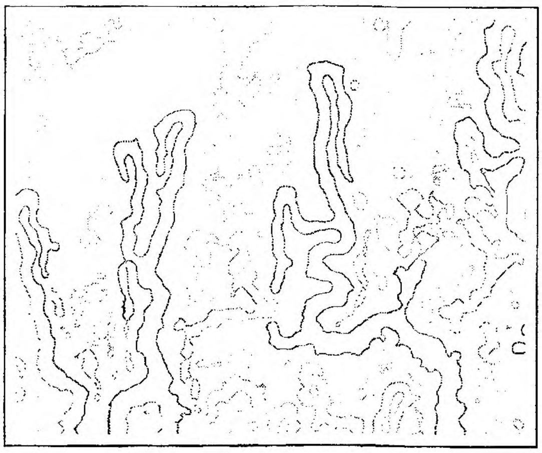


Figure 11. Resulting edge lines after the procedure of bringing to the same intensity of each separate edge line.

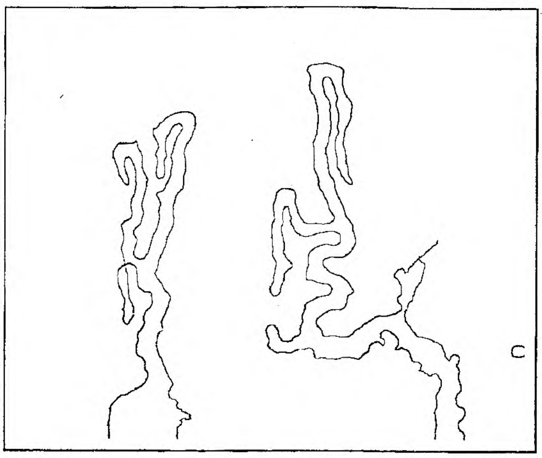


Figure 12. Resulting micro capillaries edge image after threshold binarization.

Fig. 12 shows the received capillaries edge image after clearing by means of simple threshold binarization. This edge image is ready for determining the geometric parameters of capillaries.

## 4. CONCLUSIONS

The proposed method enables obtaining the minimum width of one pixel difference, that maximize sharpness, while maintaining all the small elements of the image without making granularity on it. On the basis of this method a contouring method was proposed that have several advantages:

- the possibility to get thin edge line of one pixel width;
- maintaining edge corners and small image elements;
- continuity of edge lines;
- the possibility of brightness differentiation for edge lines to separate the useful lines from unnecessary lines.

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