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Blood Vessels Detection Using Morphological Operations and Hough Transform in CT Images

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ABSTRACT

The detection and segmentation of the blood vessels are often essential prerequisite steps in the identification of anatomy and pathology. In this study, an approach for blood vessels extraction using mathematical morphology and Hough Transform is presented. The main steps of the processing are: enhancement operation is applied to the original Computer Tomography (CT) image in order to remove the noise based on homomorphic filtration and morphological operation such as hit-miss or directly skeletonization is employed to extract blood vessels on the medial axes. For more accurate vessel tracking a Probabilistic Hough Line Transform (PHT) is applied to binary image of the skeleton modification or of selected region of interest (ROI).

Key words: Blood vessels detection, Hough Transform, morphological skeletonization, segmentation.

1. INTRODUCTION

Blood vessel delineation on medical images is used for diagnosis of the vessels (e.g. stenosis or malformations) and registration of patient images obtained at different times. In a normal vein, the cusps of the valves close to prevent backward flow of blood. In a varicose vein, the cusps cannot close because the vein is abnormally widened. Consequently, blood can flow in the wrong direction. In Figure 1 is shown an example for normal and varicose vein [1].

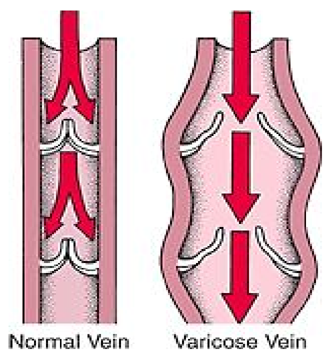


Figure 1: Example for normal and varicose vein

Vessel segmentation algorithms are used in the automated radiological diagnostic systems. Segmentation methods vary depending on the imaging modality, application domain, method being automatic or semi-automatic, and other specific factors. For example, segmentation of retinal vasculature from retinal image is used in many medicine disciplines, disease identification, biometrics or image registration [2],[3]. Palm vein recognition is used for automated personal identification [4]. There is no single segmentation method that can extract vasculature from every medical image modality. Depending on the image quality some segmentation methods may require image preprocessing prior to the segmentation algorithm [5],[6]. Some methods apply post-processing to overcome the problems arising from over segmentation [7]. Generally vessel segmentation algorithms and techniques can be divided into the following main categories: pattern recognition techniques, model-based approaches, tracking-based approaches, artificial intelligence-based approaches, neural network-based approaches, and miscellaneous tube-like object detection approaches. C. Kirbas and Fr. Quek present a detailed survey of vessel extraction techniques and algorithms in [7]. Although they divide segmentation methods in different categories, sometimes multiple techniques are used together to solve different segmentation problems.

In this paper a multistage approach is presented for CT images processing for obtaining a better visual quality for vein detection. With increased noise, low contrast soft tissue boundaries may be obscured [8]. The quantum noise is dominant and comes from the quantization of energy into photons. It is Poisson distributed and independent of measurement noise and has the characteristic of multiplicative noise [9]. For this reason we propose to be applied a homomorphic filtration on the base of wavelet packet shrinkage decomposition and adaptive threshold. The segmentation is based on morphological operations such as hit-miss operator or skeletonization for extacting blood vessels on the medial axes. For more accurate vessel tracking is applied a Probabilistic Hough Line Transform to binary image of the skeleton modification. It can be applied on a selected ROI, too.

The rest of the paper is organized as follows. In section 2 the general algorithm of the proposed approach is presented.

Section 3 introduces the details of pre-processing step. The vein detection on the base of morphological processing is discussed in section 4. Section 5 discusses the vessel tracking on the base of probabilistic Hough line transform to binary image of the skeleton modification. Some results, obtained by the simulation and discussion are introduced in section 6. Finally, conclusion is presented in section 7.

2. BASIC STAGES OF PROPOSED APPROACH

In the paper is proposed an effective approach for blood vessels detection and segmentation in CT images. It consists of following basic stages:

1) Pre-processing by complement of the original image and noise reduction of the transformed image by homomorphic filtration on the base of WPT;
2) Morphological processing of the binary image by hit or miss operator to detect objects with a specific shape and /or skeletonization for extracting medial axes.
3) Vessel tracking based on Probabilistic Hough Line Transform (PHT) to binary image of the skeleton modification or of selected region of interest (ROI).

The block diagram of the algorithm is presented in Figure1.

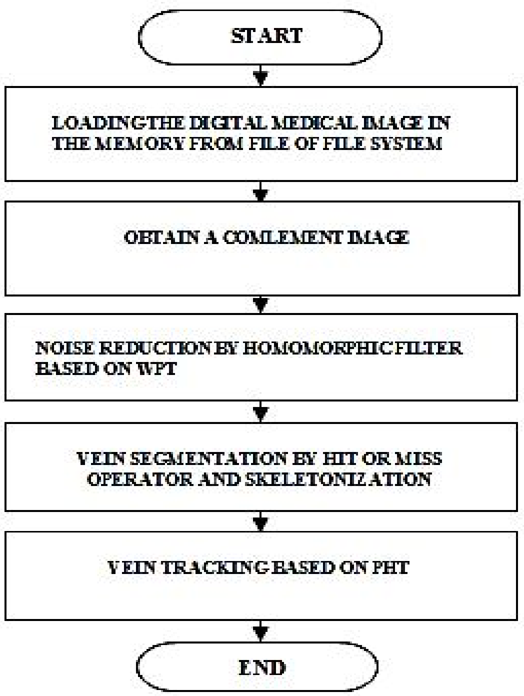


Figure 1: Flowchart of proposed algorithm

3. PRE-PROCESSING STAGE

To obtain a better visualization of the blood vessels in CT image a transformation of the original image in to a complemented image is proposed. For a greyscale CT images, each pixel value is subtracted from the maximum value that can be represented by the input data type and then outputs the difference. As result, the dark areas become lighter and light areas become darker.

The quality of CT images varies depending on penetrating X-rays in a different anatomically structures. Noise in CT arises from the fundamentally statistical nature of photon production and can appear as thin bright and dark streak artifact. The measurement noise is additive Gaussian noise and usually negligible relative to the quantum noise.

By homomorphic filtering (HF) a multiplicative noise model is transformed into additive, using a logarithmic transformation. Because of its individual characteristics, such as multiscale, spatial localization and frequency localization, wavelet transformation can be used instead of Fourier's to improve operational efficiency.

What is presented in our work is an approach for CT images denoising using improved homomorphic filtering, based on wavelet packet transformation (WPT) [10]. The improved homomorphic filtering schema is shown on Figure 3, where WPT is 2D Discrete Wavelet Packet Transformation, H(u,v) presents a filter function, IWPT is 2D Inverse Discrete Wavelet Packet Transformation, *f(x,y)* is the input image and *g(x,y)* is the output image. The method can propose a more complete analysis and provides increased flexibility according to DWT. The filtration is obtained on the basis of the best shrinkage wavelet packet decomposition and the spatial adapted threshold that allows determining the threshold in three directions: horizontal, vertical and diagonal [11]. It is proposed to use the Normal Shrink method to calculate the threshold value only for the detail sub-bands in the best shrinkage decomposition.

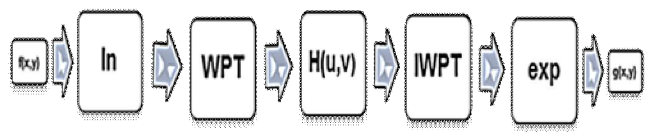


Figure 3: Flowchart of homomorphic filtering based on WPT transform

All these elements of the procedure for noise reduction can be determined on the basis of the calculated estimation parameters. PSNR and effectiveness of filtration (E_{FF}) values are higher for better denoised image where the value of noise reduction ratio (NRR) is lower.

4. MORPHOLOGICAL PROCESSING

Mathematical morphology offers classes of applications in segmentation and image enhancement. In this work a hit-miss operator is used to obtain a segmented vein as well as a skeletonization for extracting its skeletons or medial axes.

In mathematical morphology, hit-or-miss transform is an operation that detects objects with a specific shape in a binary image, using the morphological erosion operator and a pair of disjoint structuring elements. If the pattern of the element (mask) matches the state of the pixels of image under the mask (hit), an output pixel in the center pixel of the mask is set to some desired binary state; while for a mismatch pattern (miss), the output pixel is set to the opposite binary state [12],[13].

Let B_1 and B_2 be two structuring elements satisfying $B_1 \cap B_2 = 0$. The pair (B_1, B_2) is sometimes called a composite structuring element. B_1 defines a set formed from elements of B associated with an object. B_2 defines set formed from elements of B associated with the corresponding background. The hit-or-miss transform of a given image A by B= (B_1, B_2) is given by [14]:

$$A(*)B=(A \ominus B_1)\cap(A^C \ominus B_2), \qquad (1)$$

where A^C is the set complement of A.

This operation can be used for the location of isolated foreground pixels, foreground endpoints - one or zero neighboring foreground pixels, multiple foreground points, foreground contour points. In our work we propose to use this operation for the extraction of the vein shape.

The problem with hit-and-miss transform is that it cannot be used in searching similar shapes within binary images. The detection of a specific shape requires a combination of two erosion operations [15].

The skeletonization provides a simple and compact representation of the shape, preserving many of the topological and size characteristics of the original object [16],[17]. Morphological skeletons are of two kinds [14]:

- Those defined by means of morphological openings, from which the original shape can be reconstructed;
- Those computed by means of the hit-or-miss transform, which preserve the shape's topology.

Let *{nB}*, *n=0, 1, 2…*, be a family of shapes, where B is a structuring element,

$$nB = \underbrace{B \oplus ...... \oplus B}_{n \ \ times}, \text{ and } 0B = \{0\}, \qquad (2)$$

where *0* denotes the origin.

The variable *n* is called the size of the structuring element.

Lantuéjoul's formula can be discretized as follows. For a discrete binary image $X \subset Z^2$, the skeleton *S(X)* is the union of the skeleton subsets $\{S_n(X)\}$, *n=0, 1, 2…, N*, where:

$$S_n(X) = (X \ominus nB)-(X \ominus nB) \circ B \qquad (3)$$

The two kinds of skeleton can be used depending on the concrete situation. A problem with the most skeletonisation algorithms is their sensitivity to noise. Many algorithms study their sensitivity to boundary noise [16]. Also, some existing skeletonisation approaches require that many parameters be supplied by the user [18]. To solve this problem we propose to use more effective techniques for noise reduction in the pre-processing stage.

5. VESSEL TRACKING

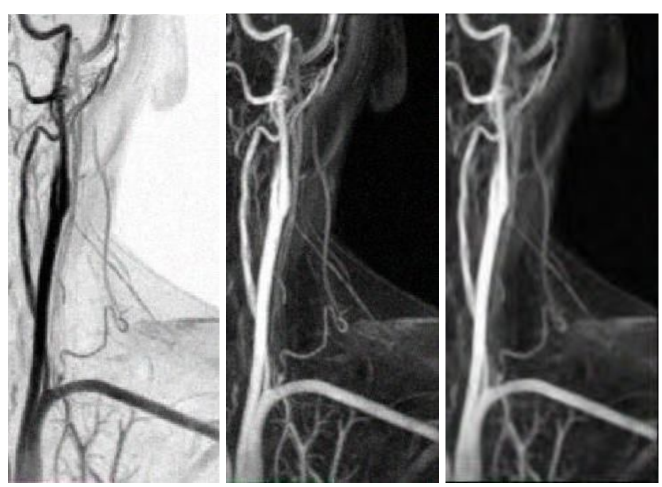
Vessel tracking (VT) approaches are used to detect vessel centerlines or boundaries by analyzing the pixels orthogonal to the tracking direction. Thus, different methods are employed in determining vessel contours or centerlines. Edge detection operation followed by sequential tracing by incorporating connectivity information is a straightforward approach [7].

It is proposed to present the skeleton of the normal veins as set of straight lines with different length. Then, a Probabilistic Hough Line Transform is applied to analyze a vessel tracking. The line can be detected by finding the number of intersections between curves. The more curves intersecting means that the lines represented by that intersection have more points. In general, we can define a threshold of the minimum number of intersections needed to detect a line. Hough Line Transform presents lines in the Polar system and keeps track of the intersection between curves of every point in the image. If the number of intersections is above some threshold, then it declares it as a line with the parameters (ρ, θ) of the intersection point. The Probabilistic Hough Line Transform gives as output the extremes of the detected lines (x_0, y_0, x_1, y_1). So can be calculated the minimum number of points that can form a line (*minLinLength*) and the maximum gap between two points, which can be considered in the same line (*maxLineGap*) [19]. Lines with less than this number of points are disregarded.

The proposed approach can be applied to the whole image or to selected ROI of it.

6. EXPERIMENTAL RESULTS

The formulated stages of processing are presented by computer simulation in MATLAB, version 7.14 environment by using the IMAGE PROCESSING and WAVELET TOOLBOXES. Thirty real grayscale CT images of veins with size 232x512 pixels are used in the analysis. The original images are obtained in DICOM, but have been archived in jpeg file format. By pre-processing they are converted in bmp format. In Figure 4 are presented the original CT image and its modifications after pre-processing stage. The obtained results can be compared with other methods such as median filter and homomorphic filtering on the base on and 2D discrete wavelet transformation (DWT). The obtained average results from the simulation are presented in Table 1.



a) b) c)

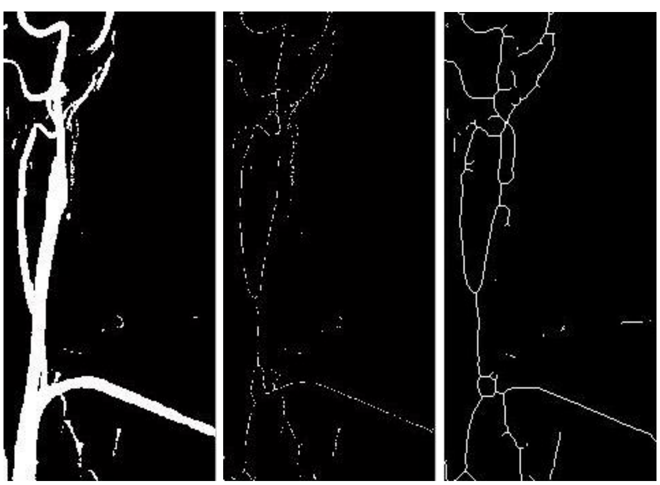
Figure 4: CT image of vein**:** a) original image; b) complemented image; c) denoised image

The obtained simulation results show that the proposed method is more effective. The value of NRR is about 0.3 and shows that the noise is three times reduced. The value of NRR by second method, based on DWT is about 0.5 and shows that the noise is two times reduced. The values of PSNR and Effectiveness of filtration (E_{FF}) for the proposed method are more sufficient.

Table 1: Simulation results of different methods for filtration

Method of noise reduction	**PSNR [dB]**	**NRR**	**SNR_Y [dB]**	**SNR_F [dB]**	**E_{FF} [dB]**
MF	23.85	0.71	15.95	16.81	0.86
HF based on DWT	25.81	0.50	15.95	17.12	1.17
HF based on DWPT	27.96	0.33	15.95	18.82	2.87

The results from the next morphological processing using hit-miss operator, hit-miss operation followed by skeletonization, and skeletonization are shown in Figure 5. The obtained results have shown that by using only skeletonization the medial axes of the vein are more accurately segmented and there is not any breaking. The operation is defined by means of morphological openings, from which the original shape can be reconstructed.



a) b) c)

Figure 5: Binary CT image of vein processed by**:** a) hit-miss operator; b) hit-miss operator following by skeletonization; c) skeletonization

In Figure 6, Figure 7, and Figure 8 are presented the obtained results from vein tracking on the base of PHT.

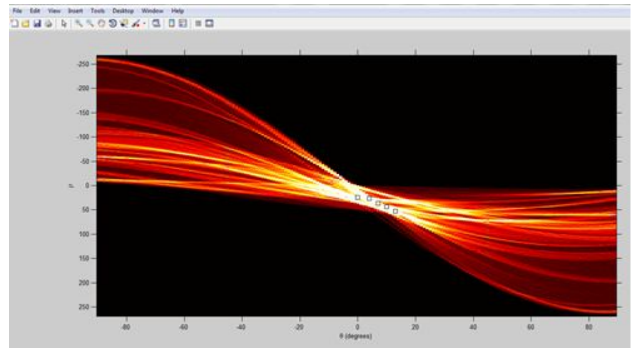


Figure 6: Vein tracking in Hough space

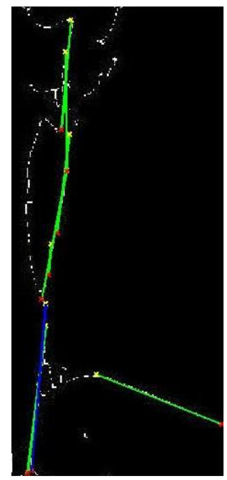


Figure 7: Binary CT image with vein tracking on the base of PHT

Figure 8 gives important information about the number of the straight line parts, its minimal and maximal length, and the coordinates of the end points of each line part.

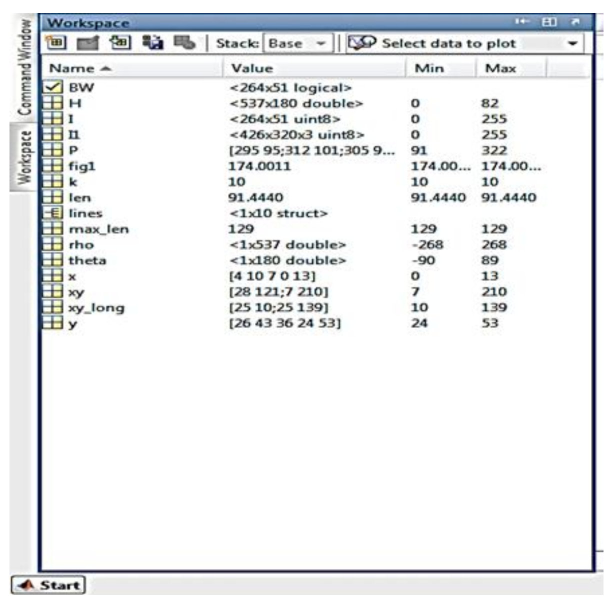


Figure 8: Obtained results from vein tracking on the base of PHT

The performance of proposed vein segmentation methodology is analyzed with the following parameters:

• Sensitivity (Se=TP/ (TP+FN))

• Accuracy (Acc= (TP+TN)/ (TP+FN+TN+FP)) where, TP denotes true positive, FP denotes false positive, FN denotes false negative and TN denotes true negative. True Positive refers to the correctly detected blood vessels, True Negative refers to the wrongly detected blood vessels, and False Positive refers to the correctly and wrongly detected non blood vessel pixels.

The experimental results have shown that, the proposed method can detect blood vessels with an average sensitivity of 78% and an average accuracy of 97.6% in the CT vein images. These parameters are depending on the quality of the input image.

7. CONCLUSION

This paper proposes effective blood vessels detection and segmentation approach, which is based on multistage pre-processing, based on improved homomorphic filter for noise reduction in CT images, morphological extraction of vein by hit-or miss operation and /or skeletonization by medial axes, and vein tracking using PHT. In this case the main disadvantage of the vessel tracking approaches, which is that they are not fully automatic and require user intervention for selecting starting and end points, can be eliminated. The obtained results from simulation have demonstrated the high segmentation accuracy and sensitivity of the proposed method, especially at regions around the vessels, where it is most important. It can be used for medical diagnostic and in biometric identification, too. The line detected areas can give information about the vein status by screening some diseases. The obtained results can be used for more precise analysis of the blood vessels and their 3D visualization.

Our future investigations will be concentrated on measurement of some parameters of the blood vessels, which can help for more precise analysis and detection of some diseases.

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