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Automatic segmentation of coronary arteries using Gabor filters and thresholding based on multiobjective optimization

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ABSTRACT

This paper presents a new method consisting of two stages for automatic detection and segmentation of coronary arteries in X-ray angiograms. In the first stage, multiscale Gabor filters are used to detect vessel structures in the angiograms. The results of multiscale Gabor filtering are compared with those obtained by applying multiscale methods based on the top-hat operator, Hessian matrix, and Gaussian matched filters. The performance of the vessel-detection methods is evaluated through the area (A_z) under the receiver operating characteristic (ROC) curve. In the second stage, coronary arteries are segmented by binarizing the magnitude response of Gabor filters using a new thresholding method based on multiobjective optimization, which is compared with seven thresholding methods. Measures of sensitivity, specificity, accuracy, and positive predictive value are used to analyze the segmentation methods, by comparing the results to the ground-truth markings of the vessels drawn by a specialist. Finally, the proposed method is compared with seven state-of-the-art vessel segmentation methods. The result of vessel detection using multiscale Gabor filters demonstrated high accuracy with $A_z = 0.961$ with a training set of 40 angiograms and $A_z = 0.952$ with an independent test set of 40 angiograms. The results of vessel segmentation with the multiobjective thresholding method provided an average accuracy of 0.881 with the test set of angiograms.

1. Introduction

Automatic segmentation of coronary arteries in X-ray angiograms has become essential for systems that perform computer-aided diagnosis (CAD), as it can help cardiologists in diagnosing and treating vascular abnormalities. The key challenges in computer-aided analysis of X-ray coronary angiograms are nonuniform exposure and low contrast between the vessels and the image background. In Fig. 1, the difficulties in coronary vessel segmentation are illustrated. The presence of multiple shaded bands along vessel segments produces histograms with several peaks and valleys; as a result, the coronary artery segmentation problem has been commonly addressed in two stages. The first stage is vessel detection, also known as enhancement, which is used to emphasize the presence of vessel-like structures and also to remove noise from the angiograms. In the second stage, a classification technique for the identification of vessel and nonvessel pixels is applied to the enhanced-angiogram image, the performance of which is evaluated using hand-labeled images (ground-truth) provided by a specialist.

1.1. Detection of blood vessels

In recent years, several methods have been proposed for automatic detection and segmentation of blood vessels in different types of medical images. Some of the proposed methods are based on mathematical morphology. The method of Eiho and Qian [1] is one of the commonly used interactive vessel segmentation strategies, because of its robustness and ease of implementation. This method uses the single-scale top-hat operator to enhance the shape of arteries, followed by the morphological erosion, thinning,

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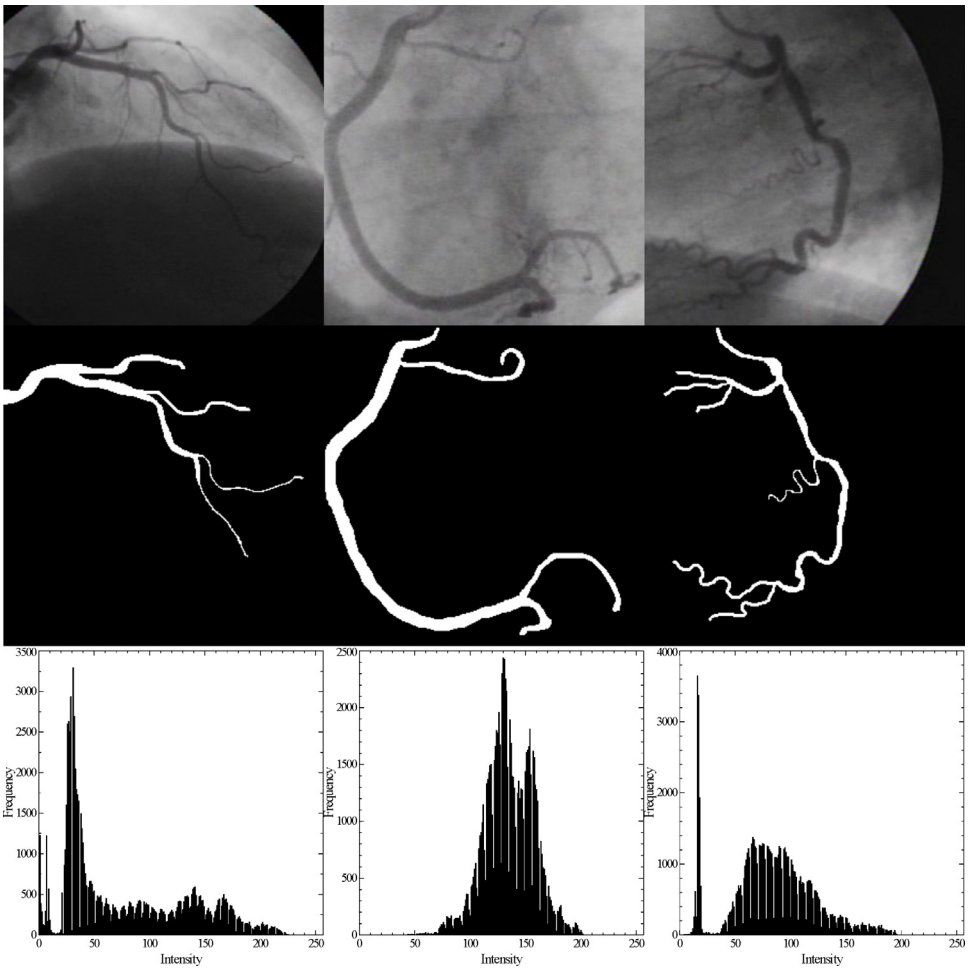

Fig. 1. First row: three coronary angiograms. Second row: manual delineations of vessels in the images of the first row, as drawn by an expert (ground-truth). Last row: histograms of the angiograms shown in the first row of the figure.

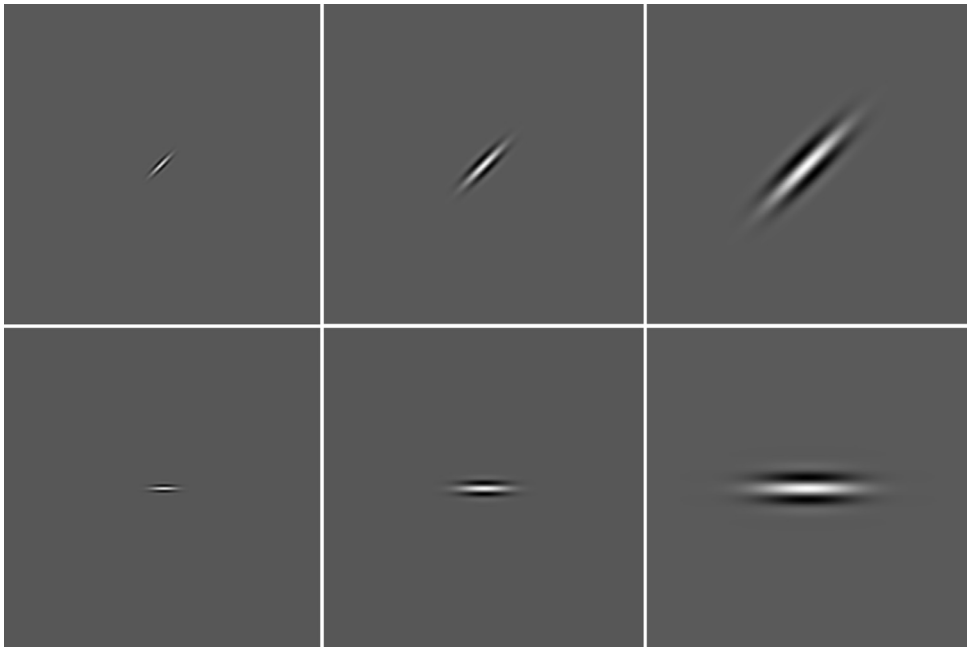

Fig. 2. Gabor filter kernels of size 300 × 300 pixels with $l = 3$. First column: using $\tau = 5$ pixels, $\theta = 45^\circ$, and $\theta = 0^\circ$. Second column: applying $\tau = 10$ pixels, $\theta = 45^\circ$, and $\theta = 0^\circ$. Last column: assigning $\tau = 20$ pixels, $\theta = 45^\circ$, and $\theta = 0^\circ$.