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On the performance of nature inspired algorithms for the automatic segmentation of coronary arteries using Gaussian matched filters

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ABSTRACT

This paper presents a comparative analysis of four nature inspired algorithms to improve the training stage of a segmentation strategy based on Gaussian matched filters (GMF) for X-ray coronary angiograms. The statistical results reveal that the method of differential evolution (DE) outperforms the considered algorithms in terms of convergence to the optimal solution. From the potential solutions acquired by DE, the area (A_z) under the receiver operating characteristic curve is used as fitness function to establish the best GMF parameters. The GMF-DE method demonstrated high accuracy with $A_z = 0.9402$ with a training set of 40 angiograms. Moreover, to evaluate the performance of the coronary artery segmentation method compared to the ground-truth vessels hand-labeled by a specialist, measures of sensitivity, specificity and accuracy have been adopted. According to the experimental results, GMF-DE has obtained high coronary artery segmentation rate compared with six state-of-the-art methods provided an average accuracy of 0.9134 with a test set of 40 angiograms. Additionally, the experimental results in terms of segmentation accuracy, have also shown that the GMF-DE can be highly suitable for clinical decision support in cardiology.

1. Introduction

Coronary angiography is an X-ray imaging procedure designed to help cardiologists in diagnosing and treating coronary artery abnormalities. In recent years, the application and development of computational methods for automatic segmentation of coronary arteries has become essential for systems that perform computer-aided diagnosis (CAD) in cardiology. The two main challenges in X-ray coronary angiograms are the uneven illumination and the weak contrast between blood vessels and image background, which are illustrated in Fig. 1. Since the nonuniform illumination along vessel structures produces multimodal histograms, the vessel segmentation problem has been frequently addressed in two stages. The first stage is vessel detection, also called enhancement, which is used to enhance vessel-like structures while removing noise from the angiogram, and the second stage focuses on applying a classification technique over the enhanced angiogram to discriminate vessel and nonvessel pixels.

Due to the importance of the automatic vessel segmentation problem, a number of computational methods have been introduced for different types of medical images. In literature, a few methods in the image frequency domain have been proposed such as Gabor filters [1–3], and wavelet transform [4]. Most of the proposed methods are computed in the spatial image domain including single-scale top-hat operator [5], multiscale top-hat operator [6,7], hit-or-miss transform [8], region-growing with differential-geometry [9], Hessian matrix [10–14], and Gaussian matched filters (GMF) [15], which have been successfully applied in retinal imaging studies [16,17].

The GMF method represents a template matching technique used for detecting vessel-like structures in the spatial image domain. GMF assumes that by using a Gaussian curve as matching template, the shape of blood vessels can be detected. Generally, the Gaussian template is rotated at different orientations, and then convolved with the input image to form a filter bank. The maximum response at each pixel is preserved to acquire the enhanced image. The appropriate performance of the GMF directly depends of four parameters, which have to be tuned in order to increase the vessel detection rate. The first parameter L determines the length of the vessel segment to be detected. The second parameter σ defines the spread of the intensity profile. The third parameter T determines the position in which, the Gaussian curve trails will cut, and the

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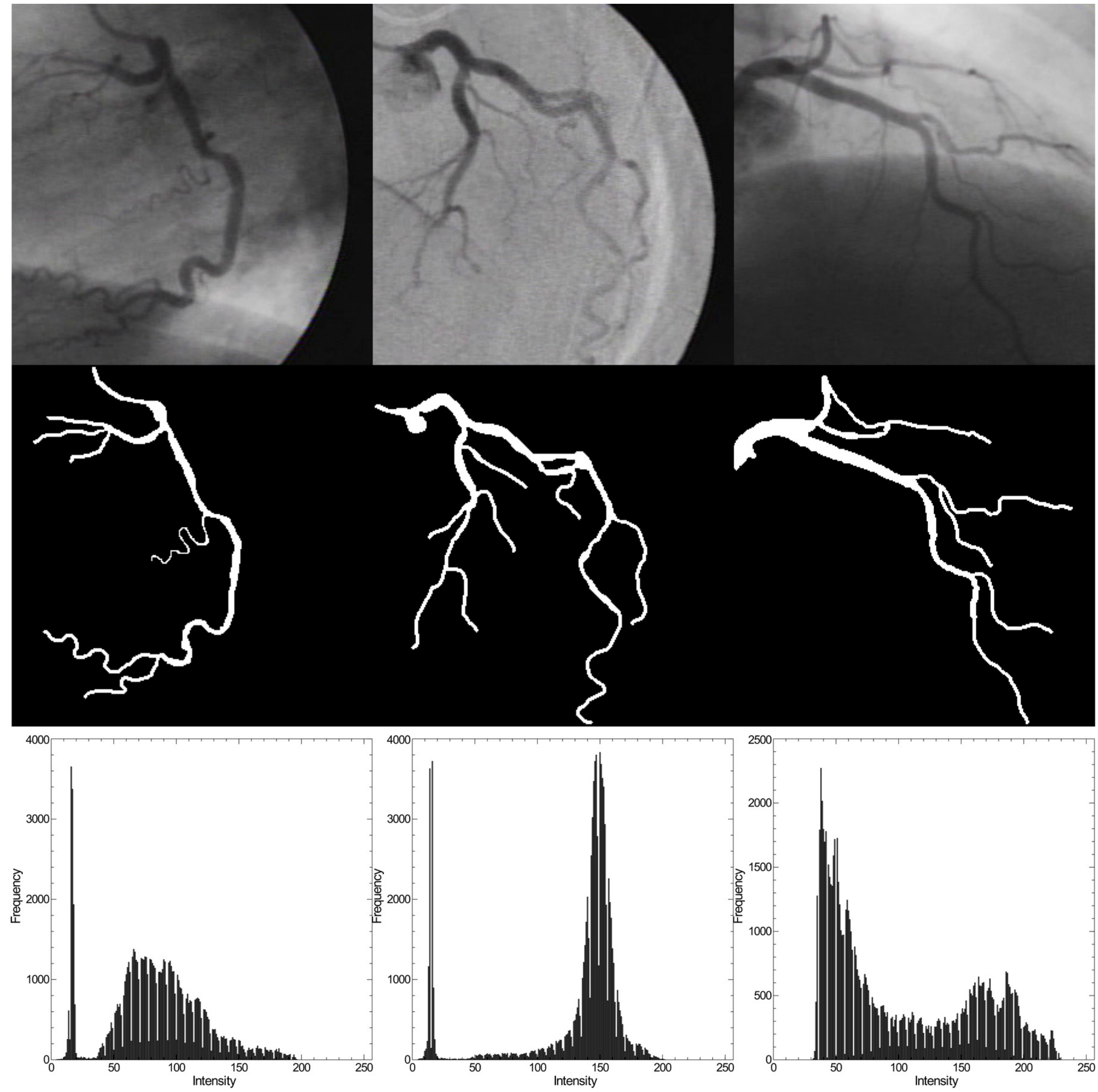

Fig. 1. First row: three coronary angiograms. Second row: manual delineations of vessels in the images of the first row, as drawn by an expert (ground-truth). Last row: histograms of the angiograms shown in the first row of the figure.

last parameter κ defines the number of evenly spaced filters with angular resolution θ.

This vessel detection technique has been successfully applied as a preprocessing stage in diverse automatic segmentation and registration methods. Chanwimaluang and Fan [16] applied the GMF as detection method followed by the local entropy thresholding technique as classification procedure to segment vessels in retinal fundus images. Subsequently, Chanwimaluang et al. [17] applied the above mentioned method, as part of a system for retinal image registration. Kang et al. [18] applied the GMF in a fusion strategy with the morphology-based top-hat operator to detect vessels in coronary angiograms. This fusion strategy was also used by Kang et al. [19,20] by applying the degree segmentation method to classify vessel pixels.

Since the GMF method was introduced by Chaudhuri et al. [15], different values for each parameter of the detection filter have been proposed. Kang et al. [18–20] proposed different values for σ and number of oriented filters κ. Cinsdikici and Aydin [21] used the original parameters of the method, just modifying the parameter of number of oriented filters κ. Al-Rawi et al. [22] proposed to apply an exhaustive search over an extended range of the variables L, T, and σ, keeping constant the number of filters. This method obtains better detection results than the aforementioned methods, taking into account the area (A_z) under the receiver operating characteristic (ROC) curve. Al-Rawi and Karajeh [23] proposed to apply the population-based technique of genetic algorithms (GAs) instead of the exhaustive search to select the optimal L, T, and σ values. According to the tests, the performance of the genetic algorithm working together with the GMF method provided better detection results than the empirically determined methods.

The population-based methods have become very popular to solve optimization problems in discrete and continuous spaces. These methods consist of a set of potential solutions, which are gradually improved by using a fitness function until a stopping criterion is satisfied. Recently, nature inspired algorithms such as particle swarm optimization (PSO), differential evolution (DE), and estimation of distribution algorithms (EDAs) have begun to attract more attention for solving optimization problems with a fast convergence including parameter estimation in computational biology [24], image segmentation [25], and cancer classification [26].