CORONARY ANGIOGRAM IMAGE ENHANCEMENT USING DECIMATION-FREE DIRECTIONAL FILTER BANKS

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ABSTRACT

The detection and enhancement of Coronary arterial trees (CAT's) in an angiogram image is an important pre-processing task that will greatly reduce the stress on further processing such as 3-D reconstruction of CAT model. Conventional techniques make use of gradient operators to detect CAT structure. However, the gradients are local operators that do not provide continuous map of arterial trees especially in noisy environment. In this paper, we propose a decimation-free directional filter bank (DFB) structure. It provides output in the form of directional images as opposed to directional sub-bands provided in previous DFBs. The presence of directional images facilitates any further spatial processing if needed. However, we have to prepare an angiogram image before it can be given as input to the proposed DFB structure due to the fact that angiograms acquired are low in contrast. The preparation steps involve removing non-uniform illumination from the image. Then proposed DFB structure outputs directional images. The final enhanced result is constructed on a block-by-block basis by comparing energy of all the directional images and picking one that provides maximum energy. The enhancement that results in the final image is due to the fact that we can separate omni-directional background noise from CAT structure which is pre-dominantly a directional feature.

1. INTRODUCTION

Angiograms are images of blood vessel structures (vasculature) that are acquired using either magnetic resonance imaging or X-Ray methods. Angiograms are required not only for diagnosis but also for treatment planning, where accurate delineation of any lesion and information concerning its blood supply is important. Typical features that clinicians look for in angiograms include the number and position of feeding vessels (arteries) as well as the way in which blood is drained from the lesion. Very often the presence of abnormal or unusual vessels structure, position or geometry may be the only clue to existence of an abnormality. Some types of lesion are associated with a specific vascular structure.

The analysis of angiogram which are high resolution X-Ray two dimensional (2-D) images containing projections of coronary arterial trees (CAT's) is done through several techniques. One such technique is biplane angiography where a sequence of usually orthogonal projection pairs is constructed. Although biplane angiogram provide information for resolving many types of ambiguity, such as artery crossing and overlapping due to projection of three dimensional (3-D) objects on the plane, the related high overhead costs have limited its use by the majority of medical labs. The other methods include single-view cine-angiograms [1], and motion estimation [2]. All the above methods are concerned with visualization of CAT's in an X-Ray angiogram.

Fig. 1. Angiogram Image

The X-ray angiograms acquired are generally, low in contrast with spatially varying average brightness, and noisy background. The example of one such image is shown in Fig. 1. Primarily, we are concerned here with enhancing angiogram image to make it suitable for further processing that include 3-D construction of CAT's structure [1]. The enhancement problem may be considered as an image segmentation problem in the sense that angiogram should be partitioned into two classes, each one belonging either to the vascular structure or the background.

From signal processing point of view, the CAT's segmentation problem can be dealt with either in spatial domain or fourier domain. The spatial domain techniques employed for CAT extraction mainly make use of gradient edge detection algorithms. Morphological edge detectors have been used for automatic recognition of arterio-venous intersection in [3]. A line finding algorithm along with a probabilistic relaxation scheme has been used for the extraction and subsequent description of blood vessel patterns in retinal images [4]. Gradient based feature extraction techniques are helpful in reliably locating blood vessels and got their motivation from enhancement of fingerprint images. However, these algorithms do not result in a continuous map of the artery trees. An individual blood vessel may be broken into several segments due to the presence of non-uniform background and the local character of gradient operator [5].

On the other hand, fourier domain CAT's extraction techniques employ sector filters to enhance directed line segment in an image but fail to produce good results in the presence of blob type objects [6]. Bamberger et.al. proposed directional filter banks (DFB) in [7] to extract directional features present in an image. Recently there has been extensive activity in the area of feature detection and image enhancement using DFB. Few examples include wavelet image denoising [8], fingerprint image enhancement [9], fingerprint image enhancement in a binary domain [10]. Since angiogram background noise is omni-directional and CAT's structure is highly directional in nature, it is conjectured that, in general, a DFB will help us in substantially reducing the noise while preserving directional features.

In this paper, we proposed a directional filter bank (DFB) based enhancement technique for X-Ray angiograms that helps in better visualization of coronary arterial trees. Furthermore, the proposed method can also be utilized as a pre-processing step in accurate reconstruction of 3-D CAT's. Our proposed DFB structure differ with the previous DFB in the sense that our proposed algorithm provides output in the form of directional images for further spatial domain processing, whereas, the previous techniques provide directional sub-bands that need interpolation to get approximated directional images [7]. The creation of directional images has been made possible in the proposed structure due to absence of decimators.

In the sections that follow we will describe first the make-up steps for an angiogram image, then develop the theory of decimation-free directional filter bank structure, discuss the creation of directional images, and finally reconstruct the enhanced image.

2. ANGIOGRAM IMAGE ENHANCEMENT

An angiogram image enhancement algorithm receives an input angiogram image, applies a set of intermediate steps on the input image and finally outputs the enhanced image. We begin with a test image shown in Fig. 1 and apply various processing steps sequentially. The details of these steps come next.

2.1. Non-uniform Illumination Correction

An input angiogram image has a varying illumination pattern that needs to be removed. Although, there are many spatial domain techniques available to get rid of non-uniform illumination structure, we opted for homomorphic filtering to extract non-uniform illumination of the test image. An image $a(i,j)$ can be expressed as a product of illumination and reflectance components i.e.

$a(x,y) = i(x,y)r(x,y)$.

By taking the natural logarithm of input image a(x, y) in the spatial domain we have transformed the image into sum of its illumination and reflectance parts. This is shown in equation form as below:

$z(x,y) = ln\{i(x,y)\} + ln\{r(x,y)\}$.

This is followed by taking discrete fourier transform (DFT) of the logarithmic image. Now based on the fact that illumination is a slowly-varying pattern that will appear as low frequency content in the fourier domain. Therefore, we applied a non-ideal butterworth lowpass filter to extract the lowpass region of the image. The transfer function of a butterworth lowpass filter of order n, and with cut off frequency at a distance D_0 from the origin is defined as

$$H(u,v) = \frac{1}{1+[D(u,v)/D_0]^{2n}}$$

where $D(u,v)$ is a radial distance from the origin. After filtering the image, inverse DFT has been applied to transform the filtered image from fourier domain back to spatial domain. Finally illumination pattern present in an image can be obtained by taking exponential of the resulting output in the spatial domain. The extracted illumination pattern can be subtracted from the test image to obtain a uniformly illuminated image as shown in Fig. 2. In our test image case, we employed D_0 as 12 and order of the butterworth filter n was 2.

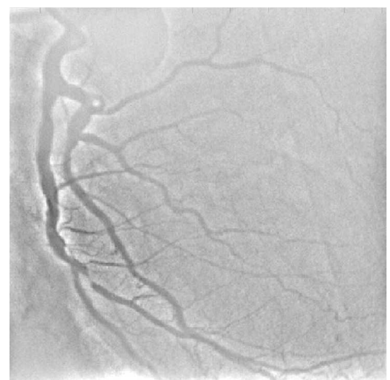

Fig. 2. Illuminated Image

2.2. Normalization

Normalization is a pixel-wise operation. The main purpose of normalization is to get an output image with desirable mean and variance, which facilitates the subsequent processing. The uniformly illuminated image is normalized by the following formula.

$$N(i,j) = \begin{cases} M_0 + \sqrt{\frac{VAR_0(img-M)^2}{VAR}} & \text{if } img(i,j) > M \\ M_0 - \sqrt{\frac{VAR_0(img-M)^2}{VAR}} & \text{otherwise} \end{cases} \tag{1}$$

Where M and VAR denote the estimated mean and variance of input image and M_0, VAR_0 are desired mean and variance values respectively. After normalization the output image is ready for next processing step.

The result of the above mentioned process is shown in Fig. 3. We note that Fig. 3 image has got its contrast back but with uniform illumination pattern.

2.3. Creation of Directional Images

This section has been divided into two sections. The first section deals with the structure for designing fan filters, while the second describes the creation of directional images employing structure of first section.

Fig. 3. Normalized Image with $M_0 = 120$ and $VAR_0 = 1200$

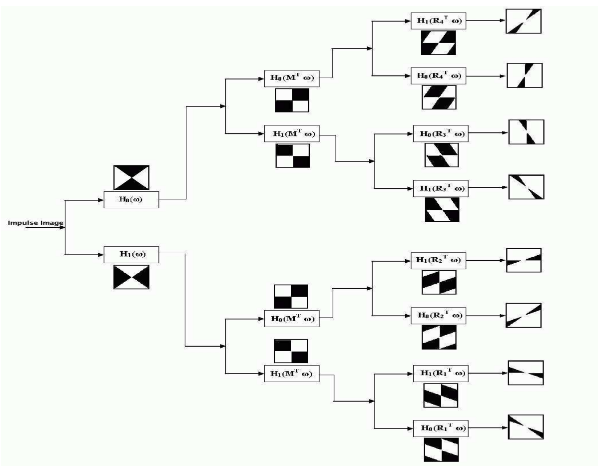

Fig. 4. Schematic Diagram of DFB

2.3.1. Design of Directional Filters

The directional analysis employed in this paper decomposes the spectral region of a given image into wedge-shaped passband regions. It is easily shown that these wedge-shaped regions correspond to directional components of an image. The filters related to wedge-shaped regions are commonly referred to as fan filters.

The schematic diagram is shown of our proposed structure is shown in Fig. 4. The structure is in the form of a tree with two-band splits at the end of each stage, where each split increases the angular resolution by the factor of two. The first stage employs the complementary hour-glass filters. The filters for next two stages are obtained by linear transformation of the first stage hour-glass filters. For implementing linear transformation, the uni-modular matrices M and R are utilized. The rules for the selection of these matrices are presented in [11]. Once the filters for each stage are implemented, we can combine them on branch by branch basis to get the required fan filters as shown at the end of third stage in Fig. 4.

One important difference between our proposed structure and DFB structure presented in [11], is the absence of decimator. It was pointed out in [7] that if sub-bands need to be processed for directional energy estimates, the decimation present in the conventional filter bank structure poses problem. This means that two samples located at the same spatial index (n_1, n_2) in two different sub-bands i and j, will not necessarily correspond to same spatial region in the original image. This problem was circumvented in [7] by employing nearest-neighborhood or bilinear interpolation to make all sub-bands of the same size. However, in our structure, decimators at each stage are taken out and filters are designed by linear transformation in the frequency domain to get fan filters. Furthermore, to avoid ringing artifact in the output, ideal fan filters are avoided by employing non-ideal hour-glass filters using an FIR lowpass filter.

2.3.2. Directional Images

The first step employed in directional images creation is to remove the spatial varying mean term by filtering with a highpass filter. In this paper, rectangularly separable highpass filter was used. The one-dimensional filter had a nominal cutoff frequency of $\pi/16$ and a 40dB stopband attenuation. The result of highpass filtering the image in Fig. 3 is shown in Fig. 5. Comparing Fig. 5 with Fig. 3, we note that arterial tree has uniform gray level throughout the image, however, in Fig. 3, arterial tree has varying gray level from black to highest gray levels.

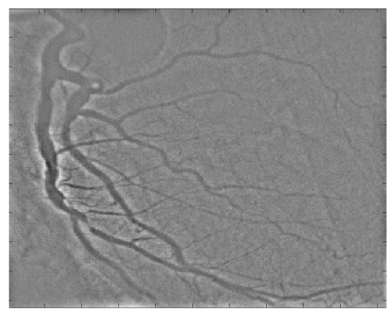

Fig. 5. Highpass Image with cutoff frequency $\pi/16$.

Directional images are obtained by applying all directional filters constructed in section 2.3.1. Four out of eight directional images obtained, are shown in Fig. 6. These directional images can be regarded as decomposition of the original image in eight pieces based on direction. Directional images contain features associated with global directions rather than local directions. By creating directional images we have divided noise of the original image into eight different directions, thus reducing noise energy eight times.

2.4. Reconstruction of Enhanced Image

Enhanced image is constructed from the directional images according to the following equation

$$f_{hf}(X, Y) = max_{1 \leq i \leq 8} f_i(X, Y), \quad (2)$$

where f_{hf} is high-frequency output image from directional filter bank and f_i represents ith directional image. For every block (X, Y) of the original image we select a replacement from the eight directional images based on maximum directional energy. Fig. 7 shows the enhanced high frequency Angiogram image. Now it is advantageous to accentuate the contribution to enhancement

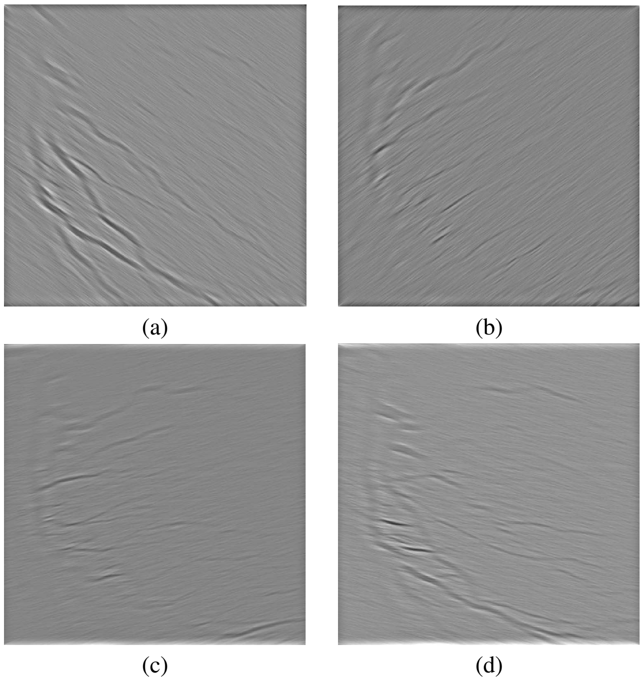

Fig. 6. Creation of directional image: a) Arteries having direction in the range 112.5-135 degrees. b) Arteries having direction in the range 22.5-45 degrees. c)Arteries having direction in the range 0-22.5 degrees. d) Arteries having direction in the range 157.5-180 degrees.

made by the high-frequency components of an angiogram image. In order to do so we adopted the well-known enhancement process referred to as *high-frequency emphasis*, where we added our enhanced high-frequency angiogram image with that of original angiogram image. The resultant image will be similar in contents to the original image but with emphasis to the high frequency features of the image. The final enhanced angiogram image thus obtained is shown in Fig. 8. We note the clarity of the CAT's structure and other detail that simply are not visible in the original image. Comparing the result with the original image shown in Fig. 1 reveals that the whole coronary tree-structure is intact while the spatial noise has been cleaned substantially.

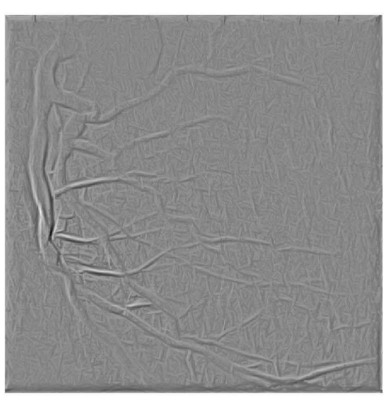

Fig. 7. Enhanced Result

Fig. 8. Final Result: high frequency emphasis

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