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Five multiresolution-based calcium volume measurement techniques from coronary IVUS videos: A comparative approach

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ABSTRACT

Background and objective: Fast intravascular ultrasound (IVUS) video processing is required for calcium volume computation during the planning phase of percutaneous coronary interventional (PCI) procedures. Nonlinear multiresolution techniques are generally applied to improve the processing time by down-sampling the video frames.
Methods: This paper presents four different segmentation methods for calcium volume measurement, namely Threshold-based, Fuzzy c-Means (FCM), K-means, and Hidden Markov Random Field (HMRF) embedded with five different kinds of multiresolution techniques (bilinear, bicubic, wavelet, Lanczos, and Gaussian pyramid). This leads to 20 different kinds of combinations. IVUS image data sets consisting of 38,760 IVUS frames taken from 19 patients were collected using 40 MHz IVUS catheter (Atlantis® SR Pro, Boston Scientific®, pullback speed of 0.5 mm/sec.). The performance of these 20 systems is compared with and without multiresolution using the following metrics: (a) computational time; (b) calcium volume; (c) image quality degradation ratio; and (d) quality assessment ratio.

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Results: Among the four segmentation methods embedded with five kinds of multiresolution techniques, FCM segmentation combined with wavelet-based multiresolution gave the best performance. FCM and wavelet experienced the highest percentage mean improvement in computational time of 77.15% and 74.07%, respectively. Wavelet interpolation experiences the highest mean precision-of-merit (PoM) of 94.06 ± 3.64% and 81.34 ± 16.29% as compared to other multiresolution techniques for volume level and frame level respectively. Wavelet multiresolution technique also experiences the highest Jaccard Index and Dice Similarity of 0.7 and 0.8, respectively. Multiresolution is a nonlinear operation which introduces bias and thus degrades the image. The proposed system also provides a bias correction approach to enrich the system, giving a better mean calcium volume similarity for all the multiresolution-based segmentation methods. After including the bias correction, bicubic interpolation gives the largest increase in mean calcium volume similarity of 4.13% compared to the rest of the multiresolution techniques. The system is automated and can be adapted in clinical settings.

Conclusions: We demonstrated the time improvement in calcium volume computation without compromising the quality of IVUS image. Among the 20 different combinations of multiresolution with calcium volume segmentation methods, the FCM embedded with wavelet-based multiresolution gave the best performance.

1. Introduction

Cardiovascular diseases and strokes together have a devastating impact on morbidity and mortality statistics and produce an immense burden in the United States and globally [1]. A cardiologist must know the exact location, position, and volume of the calcified plaque in the coronary arteries before performing percutaneous coronary interventional (PCI) procedures. An example of the LAD (left anterior descending) and RCA (right coronary artery) is shown in Fig. 1. Different methods of imaging coronary artery such as computed tomography (CT), magnetic resonance imaging (MRI), and optical coherence tomography (OCT) play a vital role in diagnosis and treatment [2,3]. Intravascular ultrasound (IVUS) is more popular on the other hand as it is comparatively less expensive, provides real-time data, and is less time-consuming [4–7].

It was very recently that teams led by Suri et al. [5,6,8,9] have been focusing on calcium volume estimation using IVUS. Recently, Suri's team [10] had compared different software segmentation methods for volume estimation from IVUS videos. This includes methods such as Threshold-based [11], K-means [12], Fuzzy c-Means (FCM) [13] and Hidden Markov Random Field (HMRF) [14]. This paper is focused on application of five multiresolution techniques in the above segmentation framework, primarily for improving the computation time for calcium volume.

Computation of accurate calcium volume is possible only if the calcium is detected all along the coronary artery [10]. Because the pullback speed is 0.5 mm/s during image acquisition, the video produced by the IVUS scanner consists of a large number of frames (approximately 2040 frames per video). Manual analysis of all the frames is (a) tedious, (b) prone to errors [6,10] and (c) consumes excessive time. To overcome the above limitations, we have developed a set of multiresolution-based automated segmentation methods that can speed up the process without losing the accuracy [15].

During the IVUS acquisition, the heart is always moving, it is important to understand which multiresolution and segmentation method combination is optimal for this setup. Multiresolution techniques can down-sample the large sized images improving the speed but storing only the low frequency components [16]. Storing only the low frequency components can cause blurring and generates artifacts [17]. This can be removed by introducing proper bias correction in the down-sampled IVUS video frames generated using different multiresolution techniques.

Multiresolution techniques are mainly divided into two categories: adaptive and non-adaptive techniques [6,18–20]. Adaptive interpolation algorithms extract image features like texture, intensity value, and edge information and use these features as landmarks for multiresolution [21]. Various adaptive techniques are context-aware resizing, segment-based, seam carving, wrapping-based, etc. [22]. The non-adaptive algorithms do not rely upon the image features; instead they are based on a direct manipulation of pixels, and hence are easy to perform and are less computationally expensive [16]. Non-adaptive interpolation techniques store only the low frequency components of

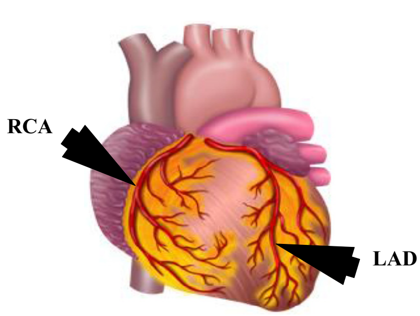

Fig. 1 – (Color image): LAD (left anterior descending coronary artery); RCA (right coronary artery) (courtesy of AtheroPoint™, Roseville, CA, USA). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)