Evaluation of a 3D Segmentation Software for the Coronary Characterization in Multi-slice Computed Tomography

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Abstract. A new generation of sub-second multi-slices computed tomography (MSCT) scanners, which allow a complete coronary coverage, is becoming widely available. Nevertheless, they need to be associated with 3D processing tools to quantify the coronary diseases. This study proposes to evaluate a new 3D moment-based method for the extraction of the coronary network and the calcification localization in MSCT. We called on two medical experts respectively in coronarography and radiology to carry out this evaluation. It was based on a comparison between extracted vessels and original scan data with objective and subjective criteria. This preliminary study has been performed on a set of six data sets, which included pathological patterns such as dense and scattered calcifications. These results confirm the good performances of the method with high scores of sensitivity and constitute a first step toward the detection of coronary networks in MSCT data.

Keywords: 3D angiography, MSCT, pathology extraction, 3D vessel detection, medical evaluation

1 Introduction

Providing a noninvasive coronary imaging is today a real challenge which is not easy to achieve due to the difficulties inherent to the observation of cardiac vascular vessels (moving and twisting structures, small diameters, connectivity with cavities and veins of the heart). Conventional X-ray coronary angiography still remains the standard of reference for the assessment of coronary-artery disease. The procedure is invasive and potentially harmful with a risk of serious event evaluated to 2% (arrhythmia, stroke, coronary-artery dissection, ...). Furthermore, the catheterization procedure involves admission to hospital and discomfort for the patient. The feasibility of noninvasive coronary imaging has been explored using different modalities, such as electron beam computed tomography (EBCT) [1] and magnetic resonance imaging (MRI) [2]. The EBCT modality gives a high temporal resolution (100 ms), with a moderate spatial resolution (0.8 x 0.8 mm).

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The MRA modality is not ionizing but has low resolution and contrast, especially with regard to the visibility of small diameter (i.e. 1 up 2 millimeters). It needs a compromise between spatial and temporal resolution (high resolution with thin slices versus apnea duration) leading to a long time of acquisition. In fact, despite encouraging results, neither of them is yet considered suitable for a clinical routine use. The recent significant advances of multi-slices computed tomography scanners (augmented gantry rotation rate – 0.5s/tr –, higher spatial and temporal resolutions with respective values such as 0.35 x 0.35 x 0.6 mm$^3$ and 105 ms), multi-detectors (from 4 to 16 detectors), retrospectively ECG-gated image reconstruction), give to this modality the means to lead to high quality cardiac and vascular examinations, providing noninvasive coronary angiography [3–4]. The clinical application field of MSCT is large including the studies of the vascular wall and the lumen as well as the analysis of the vascular environment (cardiac cavities, myocardium) from only one exam.

Most of these systems offer interactive tools to facilitate the visual analysis of 3D data set. Slice-by-slice presentation, image sequence display, or three-dimensional rendering (surface or voxel based) is now widely available and marketed. Maximum Intensity Projection (MIP) is a commonly used technique for 3D angiographies and provides a 2D projection of the 3D vessel network along a given direction. But the inherent 2D nature of the resulting image limits the value of such technique: visual occultation of vessels, artificial crossings, masking of low-intensity structures by high-intensity ones are some of the drawbacks of this technique. Simple procedures have been explored to face these difficulties by looking for the optimal viewing direction allowing disambiguating complex vessel patterns. These first steps make easier the visual reading of the image volume to the radiologist but they lead to subjective interpretation and not to quantitative features. Quantification tools still call on manual drawing and are far from fitting to the users needs. Their use requires an important effort to extract the vessel borders, compute their diameter and their cross-sectional area with enough accuracy to correctly characterize pathologies. The accurate determination of the vessel width relies on robust, precise, reproducible segmentation and characterization methods. They are expected to overcome the intra- and inter-observer variability and to improve both the diagnosis stage and the therapeutic solutions.

This paper proposes to evaluate a semi-automatic 3D moment-based method to extract the coronary network and to localize calcifications in multi-slice scanner volume data. This evaluation is done on a set of six data volumes, which contain several complex pathological cases (stenoses, calcifications, aneurysms ...). The study was led on the 16 vascular segments defined according to the classification established by the American Heart Association (AHA). A comparison was completed between the segments observed in the original 3D image and those extracted from the semi-automatic method. This comparison was based on a set of objective (robustness, computing time, interactivity) and subjective (vascular permeability, calcification) criteria, with the computing of the commonly used kappa coefficient to evaluate the similarity of information. The outline of this paper is as follows. Section 2 gives a brief overview of the current works in 3D segmentation for the extraction of vessels and describes the method based on the 3D geometrical moments. Section 3 presents the tools used for the evaluation of the vascular extracted segments. In Sect. 4, results on several data sets are provided and their analysis, conducted by two medical experts, is reported. A discussion and some prospects for future work are finally addressed in Sect. 5.