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Original Research Article

Automatic detection of coronaries ostia in computed tomography angiography volume data

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ABSTRACT

Background: Heart coronaries emerge from the ascending aorta lateral sides from two points called the coronaries ostia. To automatically segment the heart coronaries; there must be a starting point (seed) for the segmentation. In this paper we present a fully automatic approach to segment the coronaries ostia towards automatic seeding for heart coronaries segmentation.
Methods: Our algorithm takes as an input a CTA volume of segmented aorta cross sections that represents our region of interest. Then the ostia detection algorithm traverses that volume looking for the ostia points in an automatic fashion. The proposed algorithm depends on the anatomical features of the ostia. The main anatomic feature of the ostia is that it appears like a curvature or corner on the segmented ascending aorta cross section. Therefore we adopted in our methodology a modified version of Harris Corner Detection; besides inducing some anatomical features of the ostia location with respect to the aortic valve.
Results: The proposed algorithm is tested and validated on the computed tomography angiography database provided by the Rotterdam coronary artery algorithm evaluation framework. The proposed automatic ostia detection algorithm succeeded to detect both ostia points in all the test cases. Also, the detected ostia points' coordinates are validated versus a ground truth provided by the same framework with deviation between the results of the detection process and the ground truth having a min of 0 pixels and a max of 10 pixels for all test cases.
Conclusions: Thus the proposed algorithm gives accurate results in comparison with the ground truth, which proves the efficiency of the proposed algorithm and its applicability to be extended as a seed for heart coronaries segmentation.

Keywords: Coronaries ostia, CTA, Harris corner detection, Ostia automatic detection

INTRODUCTION

Nowadays non-invasive diagnosis of CAD (coronary heart diseases) is a highly adopted approach by physicians; especially for patients with low to intermediate risk.[1] To non-invasively assess for the CAD risk; physicians need to inspect the cardiac tree. The cardiac tree begins with the ascending aorta, then ostia points at the lateral sides of the ascending aorta from which the left and right heart coronaries emerge, see Figure 1. In Figure 2, we presented a fully automatic methodology to segment the ascending aorta from the aortic arch down to the ostia points, see Figure 2. Implementing an automatic technique is essential to provide a clinically convenient solution for physicians; such that they needn't do any manual work on the images.

The result of our previous work was a volume of segmented ascending aorta cross sections. In this paper, we extend the work on the resultant volume to automatically detect coronaries ostia points. Since the heart coronaries emerge from the ostia points; then it is important to detect the ostia points automatically to seed for the automatic segmentation of heart coronaries.

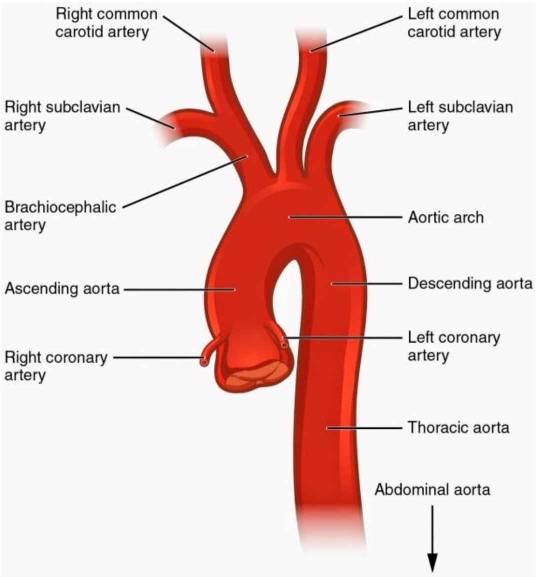

Figure 1: Aorta anatomy showing the left and right coronaries ostia.[7]

From the literature work done for ostia detection is the semi-automatic ostia detection presented in Gong et al and Hennemuth et al Gong et al. started their work by clicking a start point on the aorta top slice then region growing to segment the region of interest.[3,4] Afterwards they applied multi-scale filtering and morphologic opening operation to detect the coronaries ostia.

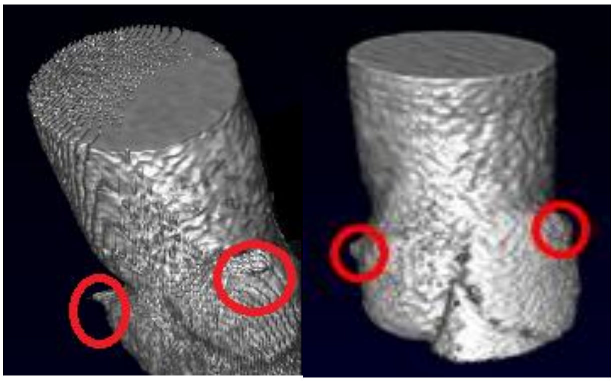

Figure 2: Ostia points indicated on two segmented ascending aorta volumes.

While Hennemuth et al set their region of interest by entering a user-defined seed point in the middle of the aorta cross section, above the first coronary artery. On the other hand, Wang et al in provided an automatic ostia detection approach but they performed extra preprocessing before the ostia detection.[5] They first removed the rib cage, then aorta tracing till detecting the coronaries roots (ostia points). In this study, we focus on providing a fully automatic technique for detecting the coronaries ostia from CTA images, with no need to add any user defined seed points or perform any extra processing on the dataset and thus provide a clinically convenient and real time approach.

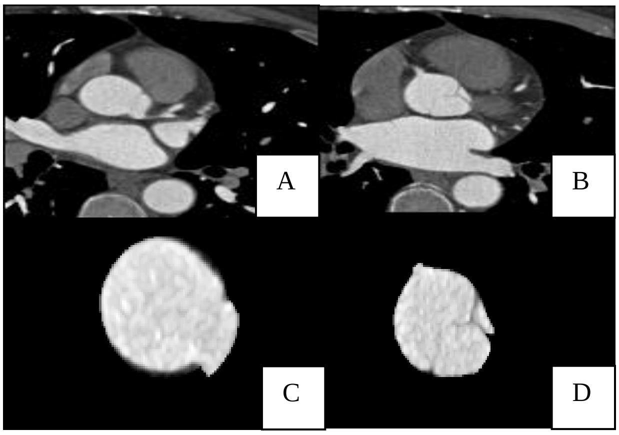

Figure 3: (a and b) Right and left ostia points (indicated by red arrows) on CTA image slices; (c and d) right and left ostia points on segmented ascending aorta cross sections.

We first take as an input the volume of segmented ascending aorta cross sections and perform ostia detection in a complete automatic fashion. Present implemented approach is based on the anatomical characteristic of the ostia that it appears like a curvature or a corner on a given ascending aorta cross section, see Figure 3. Moreover both ostia are in nearly opposite direction.[6]

These two anatomical features of the ostia points inspired us to develop a modified version of the Harris corner detection algorithm in our methodology. The Harris corner detection is used to detect all corners in a given aorta crosses section and the anatomical features are induced to help identify which corners are attributed to an ostium point.

Automatic ostia detection

The ostia represent the start points of the heart coronaries, thus ostia detection is an important step towards automatic seeding for heart coronaries segmentation. When observing the segmented ascending aorta cross sections resulting from the automatic segmentation of the ascending aorta presented in, the ostia points appear as a curvature or corner on the elliptical aorta contour, see Figure 4.[2]

This anatomical feature of the ostia makes a corner detection algorithm a good approach to adopt for detecting both ostia points. Harris Corner detection is one of the corner detection algorithms used to detect a corner in an image and since our image is already a well-defined region of interest of the ascending aorta cross sections with the ostia points appearing as a clear corner, then the detection results are anticipated to be accurate and are proven accurate after experiments are done on the CTA datasets.

Harris corner detection

A corner in an image is a significant change of intensity in all directions. Harris corner detection is one of the famous and highly cited corner detection algorithms [8]. It detects corners through shifting a local window in the image with a small amount in all directions. The highest change resulting from the mathematical formula represents a corner. The change of intensity for the shift $[u, v]$ on an image is calculated as:

$$E(u,v) = \sum_{x,y} w(x,y)\ [\,I(x+u, y+v) - I(x,y)]^2 \quad (1)$$

Where $w(x,y)$ represents the shift window, w is 1 within a region and 0 elsewhere and $I(x+u, y+v)$ is the shifted intensity. $[\,I(x+u, y+v) - I(x,y)]^2$ is near 0 for constant regions and of a large value for distinctive regions like a corner.

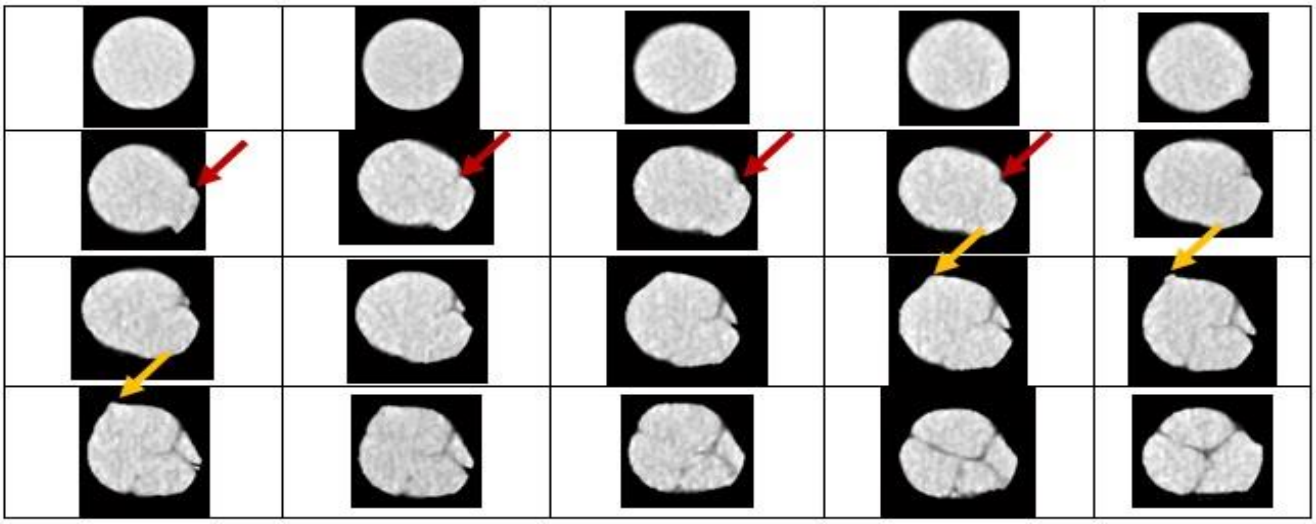

Figure 4: Segmented ascending aorta cross sections, where right and left coronaries appear as corners or curvatures on a given ascending aorta cross section (indicated by red and yellow arrows respectively).

Using approximation by a Taylor expansion and rewriting (1) in a matrix form; gives the following bilinear approximation for small shifts $[u, v]$:

$$E\,(u,v) \cong [u,v] M \begin{bmatrix} u \\ v \end{bmatrix} \quad (2)$$

Where M is 2x2 matrix computed from image derivatives:

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad (3)$$

Finally the corner response R is measured as:

$$R = \det M - K(trace\ M)^2 \quad (4)$$

Where det = λ1 λ2 and = λ1+ λ2.

R depends on the eigen values of M and to detect a corner, R should be a large positive value. K is a constant that is empirically determined. In most literature its values has been set as = 0.04 - 0.06.[9] In present work we trained our dataset to determine the appropriate range of, that makes R give a high response at corners (in our case the ostia points).

METHODS

For applying Harris corner detection on present CTA dataset: First the ascending aorta is automatically segmented from the whole CTA volume using the algorithm implemented in (2). This step defines the region of interest for ostia detection, which is the segmented ascending aorta cross sections, Figure 4.

Detecting right ostium

Harris corner detection is applied on the whole volume of segmented ascending aorta, slice by slice moving down trying to detect corners on each aorta cross section.

As can be seen in Figure 4, the aorta appears near circular/elliptical at first slices of the volume, till a curvature/corner appears which is attributed to the first ostium (right ostium), Figure 4 (indicated by red arrows).

Since first ostium appears in multiple sequential slices, the Harris corner detection will detect the first ostium on all these slices where it appears, Figure 5.

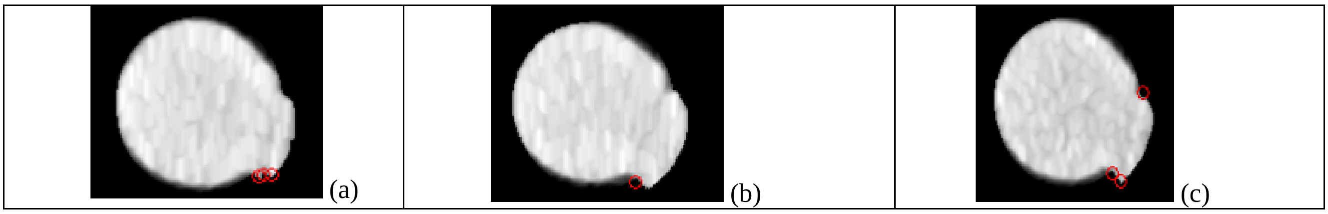

Figure 5: Right ostium detected on multiple sequential slices.

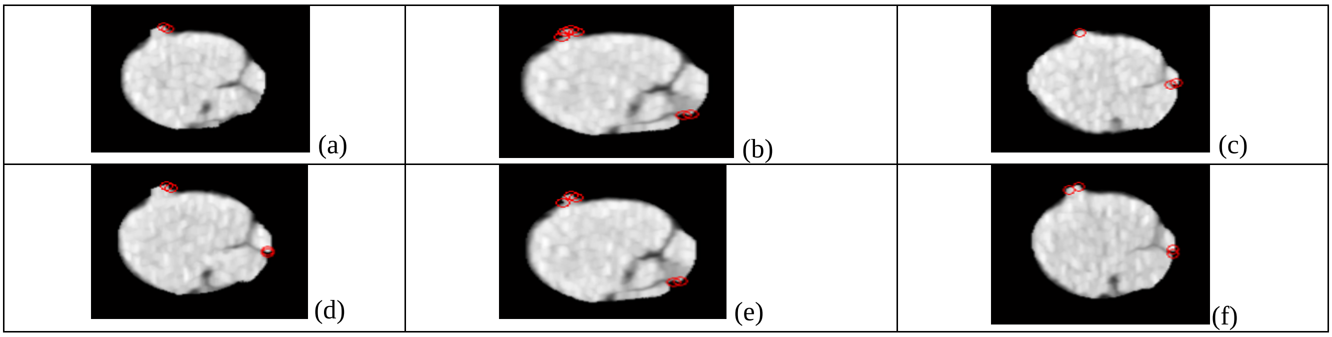

Figure 6: Left ostium detected on multiple sequential slices.

Detecting left ostium

Harris corner detection will continue moving down the segmented aorta volume to detect the second ostium. According to the position of the second ostium (left ostium) with respect to the aortic valve hinges, see Fig. 3.b; in some cases the Harris corner detection would detect multiple corners on the same slice: one at the second ostium corner and mistakenly another at a hinge corner (false positive detection) (see Figure 6b-6f).

In case of multiple corners being detected on the aorta cross section, another anatomical feature of the ostia points will be induced in the detection process; to correctly identify which corner is attributed to the second ostium in an automatic fashion.

From the anatomical point of view, the left ostium flips its curvature (appear on a near opposite direction) than the right ostium.[6] So, this anatomical feature will help correctly detect the left ostium point among other corners detected on the same slice Figure 5a. After detecting the left ostium, the detection algorithm will terminate.

RESULTS

To automatically detect ostia points, we developed a detection algorithm of Harris Corner detection augmented with anatomical features of the ostia points. The algorithm has been tested on the cardiac CTA database provided by the Rotterdam coronary artery algorithm evaluation Framework.[10]

The database includes 48 datasets. The CTA datasets were acquired in the Erasmus MC, University Medical Center Rotterdam, in Netherlands. Some of the datasets were acquired with a 64-slice CT scanner and some with a dual-source CT scanner. The implementation is done on an Intel core i5 machine with 2.50 GHz CPU, 6 GB RAM and an NVidia GeForce GT 635 M graphics card. The visualization and the rendering of the 3D segmented aorta is done using ImageVis 3D version 3.1.0.[11]

The Harris Corner Detection has been applied on the segmented ascending aorta cross sections. Both ostia have been successfully detected in all test cases; see Figure 7 for the detection of right ostium and Figure 8 for the detection of left ostium. Prior to the detection process a large kernel has been used to filter and smooth the segmented ascending aorta cross sections; removing any noise that can mistakenly be detected as a corner. For the Harris corner detection R parameter that measure the corner response; it is chosen to be the maximum among a given slice and amongst all slices, such that the max R value of a given slice is taken as an input to the corner detection of the next slice to better help detect the exact sharp corner that resembles the ostia point.

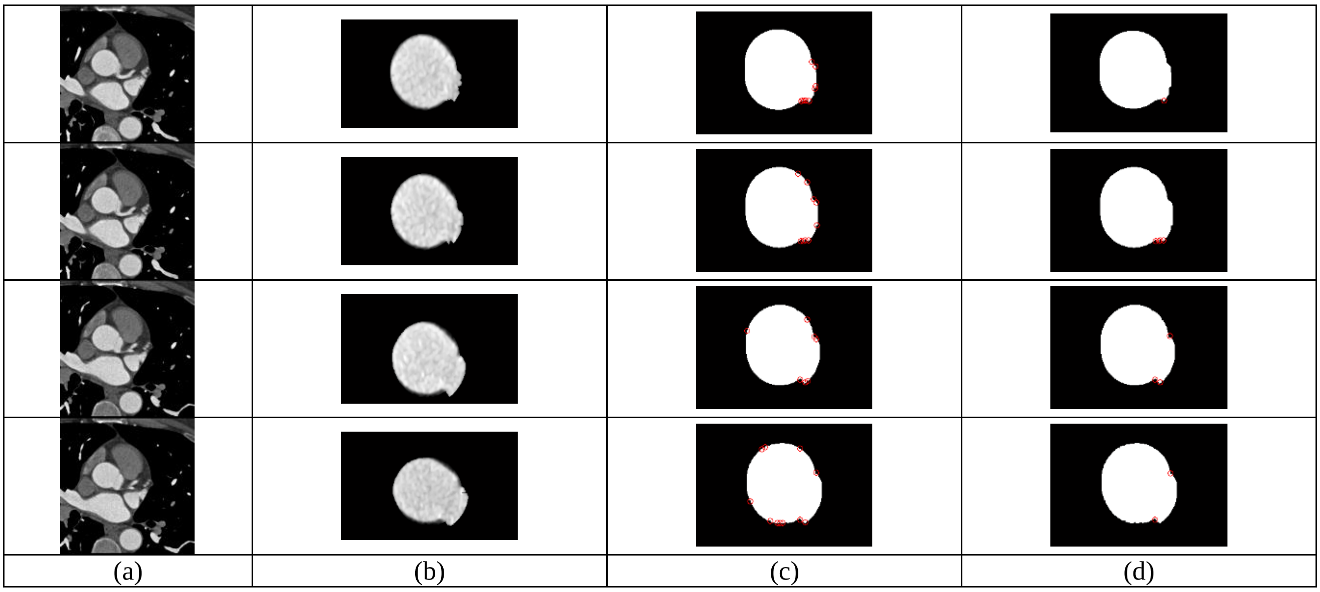

Figure 7: (a) Multiple sequential CTA slices revealing the aorta with right ostium emerging from the right side; (b) Segmented ascending aorta cross sections from the CTA slices; (c) Harris Corner detection with K=0.06; (d) Harris corner detection with K=0.2

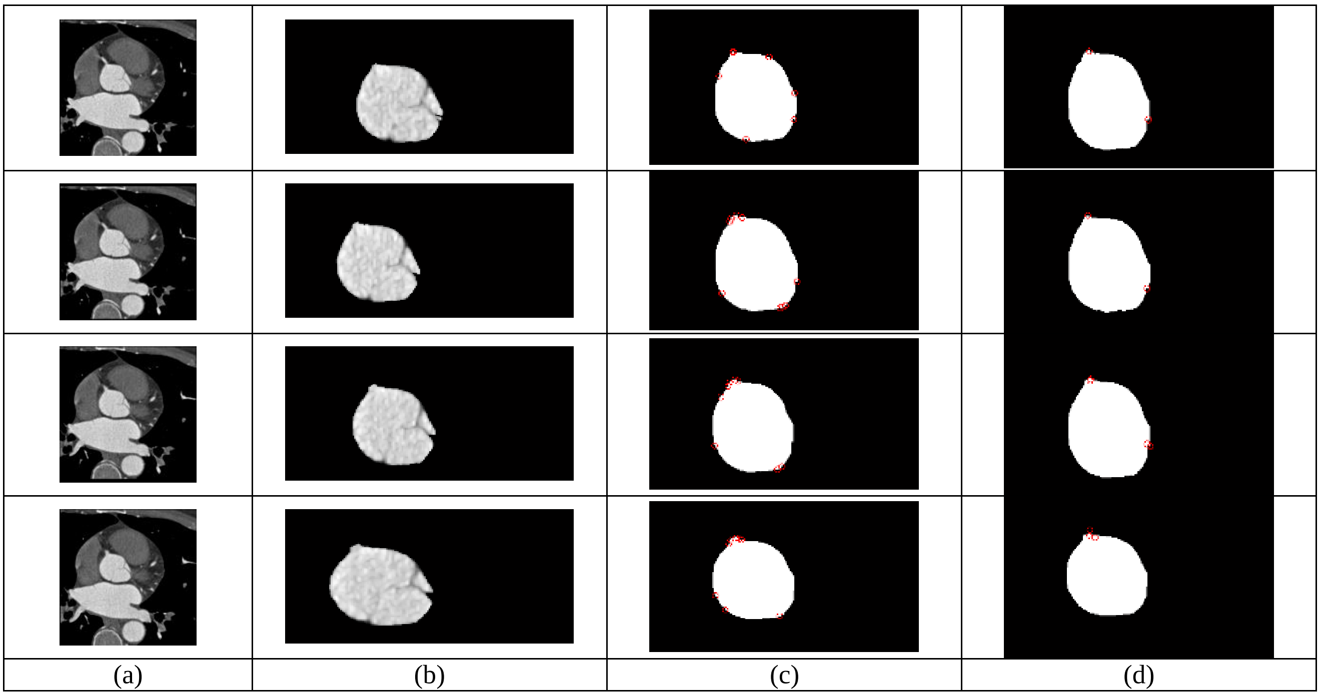

Figure 8: (a) Multiple sequential CTA slices revealing the aorta with left ostium emerging from the top left side of the aorta; (b) Segmented ascending aorta cross sections from the CTA slices; (c) Harris corner detection with K=0.06; (d) Harris corner detection with K=0.2.

DISCUSSION

After training our dataset the K parameter that govern the R response is set to the range K= 0.1-0.2, which is a range different from the one mentioned in literature k= 0.04-0.06 and is the range that correctly detects the first ostium point.[9]

The algorithm mistakenly detects multiple corners when k=0.06 and correctly detects the first ostium when K=0.2, Figure 7c-7d. For the left ostium detection, Harris corner detection correctly detects its position in some slices, see

Figure 8d, but in cases where the aortic valve hinges appear as a sharp corner, the corner detection algorithm detects them as well.

In this case, the left ostium point will be identified from any other corners detected on the same slice depending on the anatomical feature that the left ostium point flips curvature from that of the right ostium. So, the left ostium point (in terms of coordinates) will be the corner with the decreasing x value and increasing y value.

The time taken by the detection process is 35-85 seconds for volumes with 304 up to 512 slices. This time is convenient for a fully automatic approach when compared to whose work took 10-60 seconds but their approach was semi-automatic.[4]

Also, in the ostia detection process took an average of 88 seconds in addition to some preprocessing (rib cage removal and aorta tracing) that took approximately a total of 133 seconds.[5] Concerning the accuracy of the results; they have been validated versus a ground truth provided by the Rotterdam Framework.

The deviation between the results of the detection process and the ground truth has a min of 0 pixels and a max of 10 pixels over all test cases. This accuracy is better than the one presented in, who are working on the same dataset and stated a deviation in results larger than 10 pixels in some test cases.[3]

CONCLUSION

In this paper we presented a fully automatic approach to detect coronaries ostia points. Our algorithm depends on Harris Corner Detection for detecting curvatures/corners on an ascending aorta cross section. The ostia points are identified from any false positive corners by augmenting the ostia anatomical features to the detection process.

The algorithm has been tested on 48 CTA datasets provided by Rotterdam Framework and results are validated versus the ground truth provided by the same framework. The results and validation has proven the correctness, accuracy and robustness of our proposed approach, making it a reliable step towards automatic seeding for heart coronaries. Moreover the accuracy and processing time is competitive with respect to other previous related work.

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REFERENCES

1. Appropriate use of non-invasive testing for diagnosis of stable coronary artery.” [Online]. Available: https://www.escardio.org/ Journals/E-Journal-of-Cardiology-Practice/ Volume-12/ Appropriate-use-of-non-invasive-testing-for-diagnosis-of-stable-coronary-artery.
2. Seada NA, Hamad S, Mostafa MGM. “Automatically Seeded Region Growing Approach for Automatic Segmentation of Ascending Aorta,” in the 10th International Conference on Informatics and Systems. INFOS. 2016:145-50.
3. Gong Z, Shen Z, Zhang D, Wang C, Zhou S. One-click detection of coronary artery ostia from three-dimensional CTA data. 2015 IEEE Int. Conf. Inf. Autom. ICIA 2015 - conjunction with 2015 IEEE Int. Conf. Autom. Logist. 2015;877-80.
4. Hennemuth A, Boskamp T, Fritz D, Ku C. One-click coronary tree segmentation in CT angiographic images. Int Congress Series. 2005;1281:317-21.
5. Wang C, Smedby O. An automatic seeding method for coronary artery segmentation and skeletonization in CTA. Insight J. 2008:1-8.
6. Turner K, Navaratnam V. The positions of coronary arterial ostia. Clin Anat. 1996:9(6):376-80.
7. Thoracic Aorta Diagram Anatomy - Human Anatomy Chart.” [Online]. Available: http://humananatomychart.us/ thoracic-aorta-diagram-anatomy/. [Accessed: 29-Sep-2016].
8. Harris C, Stephens M. A Combined Corner and Edge Detector,” Procedings Alvey Vis. Conf. 1988:147-51.
9. Dey N, Nandi P, Barman N, Das D, Chakraborty S. A Comparative Study between Moravec and Harris Corner Detection of Noisy Images Using Adaptive Wavelet Thresholding Technique. IJERA. 2012;2(1):599-606.
10. Schaap M, Metz CT, Walsum TV, Giessen AGV, Weustink AC, Castro C, et al. Standardized evaluation methodology and reference database for evaluating coronary artery centerline extraction algorithms. Med Image Anal. 2009;13:701-14.
11. CIBC. ImageVis3D: An interactive visualization software system for large-scale volume data. 2014. [Online]. Available: http://www.imagevis3d.org.

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