A Review 3D Motion Characterization of Coronary Arteries

Lung cancer accounts for the highest incidence and mortality rates among all kinds of cancer worldwide [1]. Thus, precision treatment for lung cancer is in significant demand. Radiation therapy (RT) has become one of the main treatment for lung cancer second only to surgery. To implement high precision radiation therapy, image guided radiation therapy (IGRT) was commonly used [2]. In the process of radiation therapy for pulmonary tumor, coronary artery is one of the most vulnerable tissue. Once exposed to radiation beyond normal dose, radiation heart diseases can be caused. Quantitative description of coronary artery motion can be used for planning circumvent strategy and also for diagnosing and treating cardiovascular disease (CVD).

The motion of coronary artery is effected by both heart beating and respiration. And its movement and deformation are heterogeneous during a cardiac cycle [3]. In early works, X-Ray angiography is the main technique for visualizing the motion of the coronary arteries. And coronary motion is tracked in 2-D projection images, which is limited by the overlap of vessels [4]. In order to recover the 3-D motion information of coronary artery, the 3-D coronary tree is reconstructed for each cardiac phase in [4][5][6]. These days, due to the advance in 3-D echography, cine-MRI, and multislice computed tomography (MSCT), the 3-D CTA is available for describing the motion of full cardiac structures [8].

Few works have been devoted to the characterization of coronary artery motion. A detailed discussion on the global and local coronary artery motion features was given in [7]. The displacement and 3-D velocity of the landmarks were analyzed in [8] from MSCT angiography. A template matching method was used in modeling coronary artery motion in [9]. While in those works, coronary centerline extraction was carried out repeatedly for each phase in a cardiac cycle. The correlation between adjacent phase has not been employed to improve the effectiveness of the extraction method.

Accurate extraction of coronary centerlines is an important step for assessing the motion of coronary artery. Numerous methods has been presented for extracting coronary centerlines for 3-D CTA. Early reviews of 3-D vessel segmentation techniques can be found in [10][11]. In recent works, a machine learning-based framework for vessel segmentation [12] has outperformed the widely-used hessian-based vesselness [13] and optimally oriented flux (OOF) [14]. A graph-based method using tubularity Markov tree (TMT) was proposed in [20]. This method is proved to be more accurate and time efficient than some classical graph-based methods. For challenging image quality conditions, a generic curvature based vessel segmentation method [21] was proposed to segment the vessels by minimizing surface curvature. Example-based segmentation and component-tree were used in the extracting cerebral vascular networks [22], which has taken the advantage of expertise of the clinician to avoid possible errors. However, when the temporal dimension is added, selecting a few seed points manually for each frames could be a rather laborious task for semi-automatic extraction. Besides, the image quality of 3-D CTA sequence could be unstable due to the presence of different levels of movement artifacts. A robust and efficient vessel segmentation method dedicated to 3D+t CTA.

References

[1] World Cancer Report 2014[J]. World Health Organization, 2015.

[2] Sharp G, Fritscher K D, Pekar V, et al. Vision 20/20: Perspectives on automated image segmentation for radiotherapy[J]. Medical Physics, 2014, 41(5):050902.

[3] Husmann L, Leschka S, Desbiolles L, et al. Coronary artery motion and cardiac phases: dependency on heart rate -- implications for CT image reconstruction. Radiology, 2007, 245(2):567.

[4] Guy Shechter, Frederic Devernay, Ève Coste-Manière, Arshed Quyyumi, Elliot R. McVeigh:Three-Dimensional Motion Tracking of Coronary Arteries in Biplane Cineangiograms. IEEE Trans. Med. Imaging 22(4): 493-503 (2003)

[5] Sarry L, Boire J Y. Three-dimensional tracking of coronary arteries from biplane angiographic sequences using parametrically deformable models[J]. IEEE Transactions on Medical Imaging, 2001, 20(12):1341-51.

[6] Ruan S, Bruno A, Collorec R, et al. 3D Motion and reconstruction of coronary networks Engineering in Medicine and Biology Society, 1992, International Conference of the IEEE. IEEE, 1992:2048-2049.

[7] John Puentes, Christian Roux, Mireille Garreau, Jean-Louis Coatrieux: Dynamic Feature Extraction of Coronary Artery Motion using DSA Image Sequences. IEEE Trans. Med. Imaging 17(6): 857-871 (1998)

[8] Guanyu Yang, Jian Zhou, Dominique Boulmier, Marie-Paule Garcia, Limin Luo, Christine Toumoulin: Characterization of 3-D coronary tree motion from MSCT angiography. IEEE Trans. Information Technology in Biomedicine 14(1): 101-106 (2010)

[9] Dong Ping Zhang, Laurent Risser, Coert Metz, Lisan Neefjes, Nico Mollet, Wiro J. Niessen, Daniel Rueckert: Coronary artery motion modeling from 3D cardiac CT sequences using template matching and graph search. ISBI 2010: 1053-1056
[10] David Lesage, Elsa D. Angelini, Isabelle Bloch, Gareth Funka-Lea: A review of 3D vessel lumen segmentation techniques: Models, features and extraction schemes. Medical Image Analysis 13(6): 819-845 (2009)
[11] Cemil Kirbas, Francis K. H. Quek: A review of vessel extraction techniques and algorithms. ACM Comput. Surv. 36(2): 81-121 (2004)
[12] Matthias Schneider, Sven Hirsch, Bruno Weber, Gábor Székely, Bjoern H. Menze: Joint 3-D vessel segmentation and centerline extraction using oblique Hough forests with steerable filters. Medical Image Analysis 19(1): 220-249 (2015)
[13] Alejandro F. Frangi, Wiro J. Niessen, Koen L. Vincken, Max A. Viergever: Muliscale Vessel Enhancement Filtering. MICCAI 1998: 130-137
[14] Max W. K. Law, Albert C. S. Chung: Efficient Implementation for Spherical Flux Computation and Its Application to Vascular Segmentation. IEEE Trans. Image Processing 18(3): 596-612 (2009)
[15] M. Sabry Hassouna, Aly A. Farag: MultiStencils Fast Marching Methods: A Highly Accurate Solution to the Eikonal Equation on Cartesian Domains. IEEE Trans. Pattern Anal. Mach. Intell. 29(9): 1563-1574 (2007)
[16] Blaine Rister, Mark A. Horowitz, Daniel L. Rubin: Volumetric Image Registration From Invariant Keypoints. IEEE Trans. Image Processing 26(10): 4900-4910(2017)
[17] Dijkstra E W. A Note on Two Problems in Connection with Graphs[J]. Numerische Mathematics, 1959, 1(1):269--271.
[18] Fethallah Benmansour, Laurent D. Cohen: Tubular Structure Segmentation Based on Minimal Path Method and Anisotropic Enhancement. International Journal of Computer Vision 92(2): 192-210 (2011)
[19] Metz C T, Schaap M, Weustink A C, et al. : Coronary centerline extraction from CT coronary angiography images using a minimum cost path approach. Medical Physics, 2009, 36(12): 5568-5579.
[20] Ning Zhu, Albert C. S. Chung: Graph-Based Optimization with Tubularity Markov Tree for 3D Vessel Segmentation. CVPR 2013: 2219-2226
[21] Noha Youssry El-Zehiry, Leo Grady: Vessel segmentation using 3D elastica regularization. ISBI 2012: 1288-1291
[22] Alice Dufour, Nicolas Passat, Benoît Naegel, Joseph Baruthio: Interactive 3D brain vessel segmentation from an example. ISBI 2011: 1121-1124