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Global Optimization of Optimal Angiographic Viewing Angles for Coronary Arteries with Multiple Segments

Xuehu Wang, Jian Yang*, Tao Yang, Yongtian Wang

Abstract— **For angiographic images, different imaging angles may lead to different degrees of foreshortening and overlap, which hence considerably interferes with the angiogram based diagnosis of vascular diseases. In this study, a composite optimization method is proposed to determine the optimal viewing angle of angiograms, which can fully considerate stenosis and the interference caused due to multiple vascular segments. In order to obtain the optimal angle for segments at multiple branches' intersection, a hyper plane optimization method is proposed to separate the relative branches. The optimal angle for stenosis is designed by minimizing area of the projections of the vascular segments. The multiple segments and the stenosis optimization are integrated with the foreshortening and overlap, which can hence give a more objective viewing angle of the coronary arteries from angiographic images. Experimental results demonstrate that the proposed method is very effective and robust for optimizing the projection angle.**

I. Introduction

X-ray angiography is the most commonly used imaging modality for clinical diagnosis and treatment of coronary related diseases. As X-ray angiography is perspective projection of human anatomic structure from space to 2-D image plane, thus during this process much topological information of coronary arteries is lost. Foreshortening and overlap phenomenon are widely observed for vascular segments, which leads to great difficulties for visual inspection of diseases. Based on the vascular imaging technology, morphological structures have important clinical value for the diagnosis of coronary heart disease. However, the most suitable view for observing the vascular lesions can be presented to the experts in the optimal angiography viewing angle. In recent years, research on the optimization methods of the angiography viewing angles has attracted many researchers' attention. Coronary angiographic images are the main basis of the diagnosis and treatment process of coronary heart diseases in clinics [1]. The projection foreshortening and overlap caused by the imaging process of coronary angiography are the main parameters for clinical vascular quantitative analysis.

Christiaens [2] and Dumay [3] assumed the vascular segment as straight line and the beginning and the ending of the vessel segments were selected in two images of different projection angles. Then the optimal angiographic viewing angle was obtained through the geometry relationship of corresponding vectors. But the overlapping of vessels was not considered in this method and was only suitable for vascular of small curvature. Chen *et al.* [4] first proposed the Minimum vascular Projection Foreshortening Rate (MPFR), which was calculated to obtain the projection angle range. After that the Minimal Angles of vascular Projection Overlapping Rate (MAPOR) were filtered from this range. But this method required calculating the pixel intersection not only in the interested vascular segments, but also in the other parts of the vascular tree, which caused large amounts of calculation. Sato *et al.* [5] regarded the center of the interested vessel segment centerlines as the coordinate center. Then the ball coordinate system was established in the 3-D model of the reconstructed coronary artery, which needed to make sure that the projection direction of vascular projection foreshortening was minimized through the system center and laid in the circular plane whose normal vector can be represented by interested vessel segment direction. So in the process of calculating vascular overlap, it was only necessary to calculate the intersected vessel segment of the circular plane and to reduce the amount of calculation. Generally, this method only needed to select the projection direction within some areas of circle plane to increase the selected limitation of projection angle.

Until now relevant literatures have optimized the method proposed by Chen and they have efficiently solved the optimal angiography viewing angle problem of single interesting vessel segment. Kitslaar [6] and Green [7] introduced the concept of internal overlap. But this method ignored the problem of observation angles with very small distance between two internal vessels. The whole vascular segment was chosen as interested vessel segments in all the above methods. When we happen to suffer from the problem with lesion in vascular bifurcation points, the vessel segments cannot be accurately extracted.

According to the above observations of problems of optimal angiography viewing angle, this paper proposes a novel method of optimization process with MPFR, the maximum projection stenosis rate (MPSR), the maximum projection adjacent spacing (MPAS) and MAPOR as the optimized conditions at the same time. With the proposed method we can effectively solve the problem of projection angle optimization with multiple branch interested vessel segments. Also the major contribution of this technique to the current clinical practice will be to eliminate the human intervention required earlier for adjusting the rotational angles. This algorithm finds the optimal rotational angle automatically and excludes the human involvement at all.

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II. METHODS

Based on the coronary artery imaging technology, this paper proposes an improved method to obtain the optimal angiography viewing angle. Two optimization conditions are mainly added according to the traditional optimization method. MPSR is proposed to solve the problem of vessels with asymmetric stenosis and MPAS is proposed to solve the internal overlap problem. The flow chart of the algorithm is shown in Fig.1.

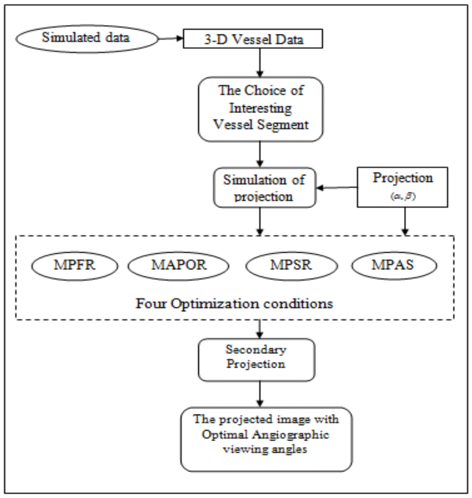


Figure 1. Flow chart of algorithm.

A. MPFR optimization

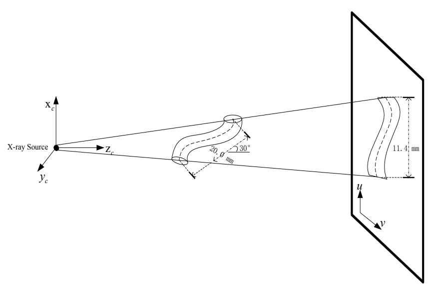


Figure 2. Projection foreshortening.

As shown in Fig.2, the centerline of the interested vessel segment lies in the direction of X-ray bundle which is vertical to the projection plane. θ is the angle between X-ray projection and vessel segment direction. The 3-D length of interested vessel segment is L , the corresponding projection length is l . The relationship between L and l is:

$$l = \eta L \sin\theta \qquad (1)$$

where η is the perspective amplification coefficient. The vascular projection foreshortening percentage F_f can be calculated as:

$$F_f = \frac{L - l}{L} = (1 - \sin\theta) \times 100\% \qquad (2)$$

when the projection angles (α, β) are known and multiple interested vessel segments $L = \{L_1, L_2, \ldots L_k\}$ are to be obtained, the vascular projection foreshortening percentage F_f in eq. (2) can be evaluated as:

$$F_f(\theta) = \left(\frac{\sum_{i=1}^{k}\sum_{j=1}^{m_i} \left|\vec{v}_{ij}\right| (1 - \sqrt{1 - \cos^2\theta_{ij}})}{\sum_{i=1}^{k}\sum_{j=1}^{m_i} \left|\vec{v}_{ij}\right|} \right) \times 100\% \qquad (3)$$

where m_i is the number of the selected points on the center of the vessel L_i and K is the number of vascular segments. $\vec{v}_j$ is the tangent vector on point t_j of middle line of $C(t)$. $\left|\vec{v}_j\right|$ is the module of $\vec{v}_j$, $0^\circ \le \theta_j \le 180^\circ$ is the angle between $\vec{v}_j$ and $\bar{z}_p$. $\bar{z}_p$ is the unit vector of the projection direction $\bar{z}_p = [-\cos\beta\sin\alpha, -\sin\beta, \cos\beta\cos\alpha]^T$.

Then, MPSA can be defined as:

$$\alpha^*, \beta^* = \arg\min F_f(\alpha, \beta) \qquad (4)$$

B. MPSR optimization

As shown in Fig.3, (b) and (c) represent the unilateral stenosis. MPSR optimization should minimize the projection area. o is the center line of the vessel and r is the radius of the vessel.

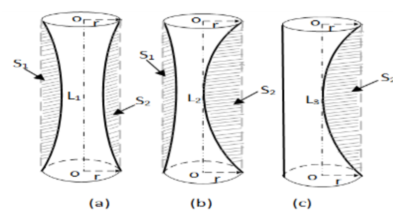


Figure 3. Stenosis of vessel: (a) represent the even stenosis. (b) represent the uneven stenosis. (c) represent the unilateral stenosis.

Assuming S_k is the corresponding projection of the interesting vascular segment L_k . The objective function is defined as following:

$$S_k = \min_{\alpha,\beta} \left(\sum_{q=1}^{N_k} V_q(u,v) \right) \qquad (5)$$

where $V(u,v)$ are the projection coordinates of L_k , N_k is the upper limit of the projection pixel number.

C. MPAS optimization

As shown in Fig.4 (a), when interested vessel segment is a multiple branch vessel, the internal overlap is also an important factor for clinicians to observe the vascular structure lesion. This paper selects hyper plane to solve effectively the problem of internal overlap and internal nearby vessels.

The hyper plane between two internal vessels is defined as:

$$w^T x + b = 0 \qquad (6)$$

where w is the normal vector of hyper plane. b is the nearest distance between the 3-D vessel points and hyper plane.

In order to obtain the optimal observation angle, we need to calculate the distance (d_1 and d_2) between the hyper plane and two vessels respectively. It was also required to set a threshold γ to ensure the distance (d_1+d_2) is slightly larger than the distance d between the centers of two vessels. The distance between vessel k and hyper plane can be defined as d^k. Then relationship is established as following:

$$\gamma^k = z^k(w^T x^k + b) = \|w\| d^k \quad (7)$$

So the process of searching the optimal hyper plane can be turned into calculating the largest sum of the nearest distance from vessels to the hyper plane, as following:

$$\max_{\gamma,\omega,b} \frac{\hat{\gamma}}{\|w\|} \quad (8)$$

where $z^k(w^T x^k + b) \geq \hat{\gamma}, k=1,2,\cdots$. Then $\hat{\gamma}=1$ can be achieved by adjusting w. Then equation (2) is extended as following:

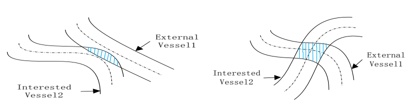
$$\min_{\gamma,w,b}\left(\frac{1}{2}\|w\|^2\right) \quad (9)$$

According to the equation (8), w is turned into solving its dual problem. This paper uses Lagrange function:

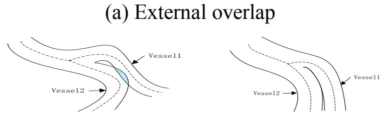
$$L(w,b,\alpha) = \frac{1}{2}\|w\|^2 - \sum_{i=1}^{l}\alpha_i(y_i\cdot((x_i\cdot w)+b)-1) \quad (10)$$

Then, MPAS optimization can be changed into a quadratic programming problem to get w. Eventually, the projection direction is set to be orthogonal to the normal vector of hyper plane as much as possible.

D. MAPOR optimization



(a) External overlap



(b) Internal overlap

Figure 4. Overlap of vessels: (a) represent the external overlap. (b) represent the internal overlap.

As shown in Fig.4(b) represents the internal overlap of vessel. The blue area represents the overlap part. The same as in the section 2.2, S_k is the projection image of L_k. $L_i\,(i=1,2,\ldots,m)$ is the internal vessel. Therefore, the overlap rate is defined as following:

$$F_o(\alpha,\beta) = \frac{\prod_{\alpha,\beta}\left(S_k \cap \left(\bigcup_{i=1,j\neq k}^{m}\right)\right)}{\prod_{\alpha,\beta}(S_k)} \times 100\% \quad (11)$$

where $\prod_{\alpha,\beta}(S_i)$ is the number of pixels in the projection image (S_i) from 3-D interested vessel (L_i) with angle (α,β). $\bigcup_{i=1,j\neq k}^{n}$ is the number of pixels in projection image from internal vessel.

III. EXPERIMENTAL RESULTS

In order to evaluate the performance of the proposed method, a series of clinical MSCT simulated angiographic vessels are tested.

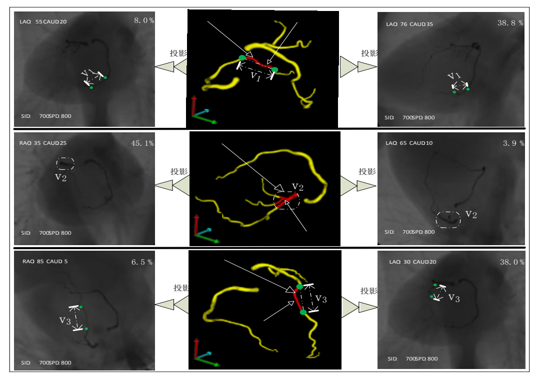


Figure 5. Projection results with different angles.

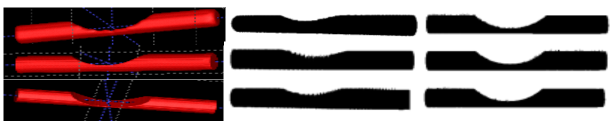
Fig.5 shows an example of the projection process. The middle column shows the 3-D reconstruction results of the vessel. The red segment is the interested segment of the vessel and the yellow segment is the external segment of the vessel. It is assumed that the interested segment of the vessel contains stenosis and the arrow pointing to the vessel describes the stenosis region. The first and the third column show the projection images at different angles and the segment of the vasculature in the white circle area is the interested one. The upper portion of every figure respectively shows the projection foreshortening rates and the projection angles. They describe different imaging angle has different foreshortening rate.

TABLE Ⅰ. FORESHORTENING RATE WITH DIFFERENT VASCULAR SEGMENTS AND ANGLES

	Segment Ⅰ (V_1)			Segment Ⅱ (V_2)		
A	*Shorten*	*Overlap*	*Narrow*	*Shorten*	*Overlap*	*Narrow*
-90	37.6	27.1	13.0	31.0	21.9	07.7
-75	38.8	28.8	14.4	39.4	29.0	11.2
-60	38.4	28.3	14.9	49.3	36.4	14.7
-45	34.8	25.5	09.0	59.8	42.8	17.0
-30	29.8	21.5	10.1	66.2	45.1	17.3
-15	22.6	17.3	14.4	55.5	38.9	15.5
0	18.3	14.3	12.4	37.8	28.3	12.3
15	21.7	13.4	10.0	23.8	18.6	09.1
30	26.3	14.7	08.8	14.7	11.9	10.1
45	30.2	17.5	08.0	11.6	09.2	05.0
60	33.4	21.0	10.0	14.9	10.7	03.9

75	35.7	24.3	11.4	23.3	15.6	05.0
90	37.6	27.1	13.0	31.0	21.9	07.7

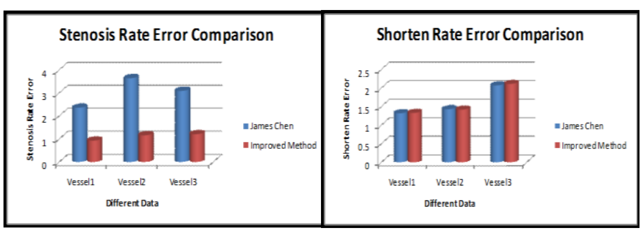
TABLE.1 shows the foreshortening rate of different interested vascular segments and angles. The table describes the foreshortening rate, overlap rate and stenosis rate of different angles. From the table it can be found that the interested segment Ⅰ can obtain the minimum foreshortening rate in the case of $\alpha = 15^{\circ}$, meanwhile, the interested segment Ⅱ corresponds to $\alpha = 45^{\circ}$.



(a) 3D-Data (b) James chen (c) Improved

Figure 6. The results of optimal angle projection:(a)3-D Data.(b)James chen's method. (c)Improved method.

Fig.6 shows the results of projection with the optimal angle obtained by the classic method and the improved method respectively. (a) Shows the original data with unilateral stenosis. (b) Shows the result of Chen's method and (c) depicts the result of the improved method. From this figure, it can be seen that the unilateral stenosis disease cannot be shown clearly with Chen's method, but it is clearly visible with the improved method.



(a) Stenosis (b) Shorten

Figure 7. Error comparison:(a)Stenosis error.(b)Shorten error.

Fig.7 shows the comparison of error with classic method and improved method. (a) shows the stenosis error, and (b) shows the shorten error. Under the condition of the comparative shorten rate, the projection stenosis error is reduced greatly with the improved method.

When the interested segment is multiple branch vessel, as shown in the middle image of the second line in fig.5 the process of MPAS and MAPOR can be combined with each other. The external and internal overlap can be calculated at the same time and the combined overlap rate is shown in table1. It can be seen that the minimum overlap rate of segment Ⅱ of projection angle 45° is 9.0%.

Fig.8 shows the projection results of multiple branch vascular segments of different angles. (b) is the result of optimal angiographic viewing angle. (a), (c), (d), (e) and (f) are the results of other angles. The segment in the blue circle is the interested vessel. Though (b) is not the angle of smallest foreshortening rate but it is the optimal angiographic viewing angle obtained by optimization method proposed in this paper. Here the projection angle satisfies all the proposed conditions.

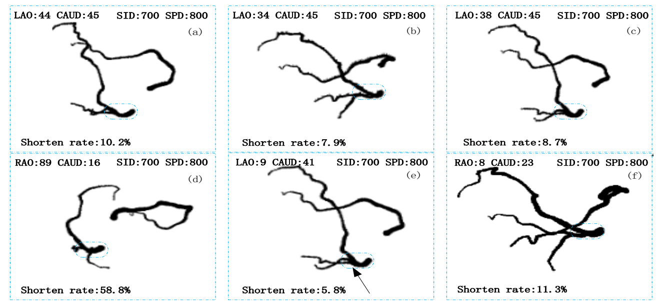


Figure 8. Projection results of multiple branch vascular segment with the projection angle and foreshortening rate of each graph

IV. CONCLUSION

Optimal angiographic viewing angle can assist in diagnosis and treatment of vascular lesions. In this paper, an optimization algorithm is proposed for the optimal viewing angle of multiple branch vascular segments and this method has four optimization conditions, which include MPFR, MPSR, MPAS and MAPOR. Among them, MPSR and MPAS are proposed for the first time in our paper to realize the optimization of the projection angle. Through this method, the most suitable view for observation vascular lesions image is presented to users. The results of the simulation experiment show that the proposed method can better realize the optimization of the optimal viewing angle for multiple branch interested vessel.

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