Three Dimensional Reconstruction of Coronary Artries from Two View X-Ray Angiographic Images

Milindkumar V. Sarode and Prashant R. Deshmukh

Abstract—**Three dimensional reconstruction of coronary arteries from two view X-ray angiographic images is a prevailing approach which recompense the limitations in X-ray angiography. Precise inspection of the multifaceted arterial network can be carried out by the physicians. In this article, mathematical modeling of two view angiography is studied. Using the principle of pinhole camera model and on the basis of existing methods, 3-D reconstruction algorithm for two view angiographic images is developed. The parameter estimation method is utilized for modification of the three dimensional structure of the vessel frames. The advantage of this 3-D reconstruction method is to be independent of the angiography acquisition system.**

Index Terms—**Angiography, coronary artries, skeleton, monoplane angiograhy, medical imaging**

I. Introduction

The importance of angiography has diminished significantly with the availability of CT and MR imaging. It is no longer used for the routine diagnosis of brain tumors. Its role is limited to, 1) preoperative evaluation of the vascular anatomy in certain patients (e.g. sphenoid voing meningioma encircling the carotid artery); 2) assessment of the patency of venous sinuses in extra cerebral tumors.

X-ray angiography is a persistent imaging system in medical practice to support coronary diagnosis and treatment. However numerous alternatives to X-ray angiography are to be developed, such as magnetic resonance angiography (MRA) [1], 3-D ultrasound [2], X-ray angiography remains the bullion standard for the diagnosis and treatment planning of coronary artery disease.

In monoplane angiography system, the physician can only obtain single angiogram from one angle of projection and it is difficult for a learner physician to diagnose disease from inadequate angiograms. While the number of different projection angles may be increased, this approach escort to higher X-ray exposure for both the patient and the physician and may result adverse effect due to major amount of radiopaque contrast material.

A variety of techniques have been developed for the 3-D reconstruction of coronary arteries from two angiograms. These methods can be alienated into two categories, first, the method can be classified according to the type of angiographic instrument used for reconstruction, may be a monoplane system [3]-[8], and a biplane system [9]-[11]. Among them, the monoplane angiographic system is the most commonly used instrument for coronary intervention therapy and methods developed on a monoplane system can also be used for biplane and rotational angiographic system [12]-[13]. For the calibrated method, independent calibration steps are performed to decide the intrinsic parameters of the equipment. The extrinsic parameters are calculated with the pinhole camera model. For the uncalibrated methods minimum number of correspondences is determined by direct inspection of the projections.

In this article, an effective method is introduced for the 3-D reconstruction of coronary arteries from two monoplane angiographic images. The angiograms used for the experiments are acquired from routine medical practice. Imaging parameters such as SID and SOD are obtained from the DICOM image files.

The paper is organized as follows. Section II gives brief idea about coronary arteries, Section III describes a mathematical modeling of pinhole camera, Section IV presents 3D structure of the vascular skeletons, Section V describes the method of 3D reconstruction of X-ray angiography images. The experimental results are shown in Section VI and Section VII provides the conclusion followed by references.

II. Coronary Arteries

The main function of the coronary arteries is to supply blood to the heart. The major coronary arteries branch off from the aorta near the point where the aorta and the left ventricle meet. These arteries and their branches supply blood to all the parts of the heart muscles. Fig. 1 gives brief idea about the frame structure of coronary arteries. The right coronary artery categorized into 1) Right marginal artery and 2) Posterior descending artery.

The main part of the right coronary artery provides blood to the right side of the heart. Fig. 2 shows collateral circulation of the vessels. The left coronary artery branches into; 1) circumflex artery and 2) Left anterior descending artery. The left coronary arteries supply blood to the left atrium and back of the left ventricle.

Manuscript received August 31, 2011; revised November 1, 2011.
Milindkumar Sarode is with the Jawaharlal Darda Institute of Engineering and Technology India (e-mail: parthmilindsarode@rediffmail.com).
Prashant R. Deshmukh is with College of Engineering Amravati India. He is now with the Department of Computer Science and Engineering (pr_deshmukh@yahoo.com).

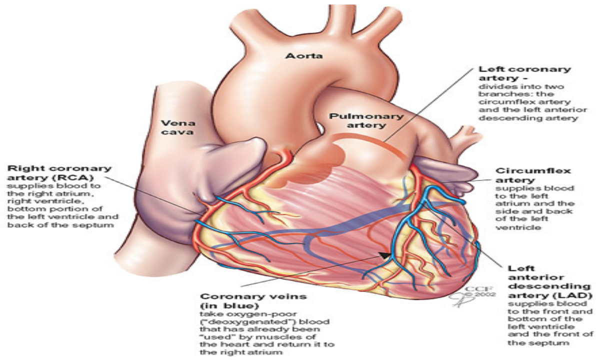

Fig. 1. Frame structure of coronary arteries of the heart.

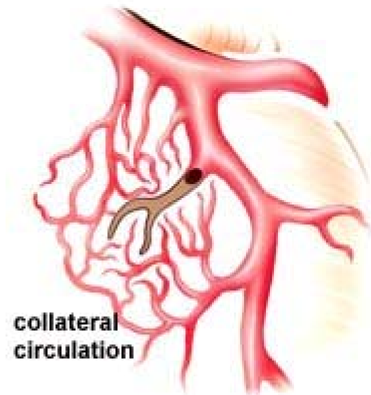

Fig. 2. Collateral circulation

III. Pinhole Camera Model

The pinhole camera model illustrates the mathematical relationship between the coordinates of three dimension points and its projection on to the image plane. Figure 3 shows the geometrical and mathematical projection of pinhole camera.

The figure includes the following objects.

1) A 3D orthogonal coordinate system with origin O. The three axes of the coordinate systems are referred to as x1, x2, and x3. Axis x3 is directing the viewing direction of the camera and is known as the optical axis.
2) The image plane is parallel to axes x1 and x2 and is sited at the distance 'f' from the origin in the negative direction of the x3 axis.
3) A point 'R' is referred to as the image centre.
4) 2D coordinate system in the image plane with origin 'R' and axes y1 and y2 are parallel to x1 and x2 respectively.

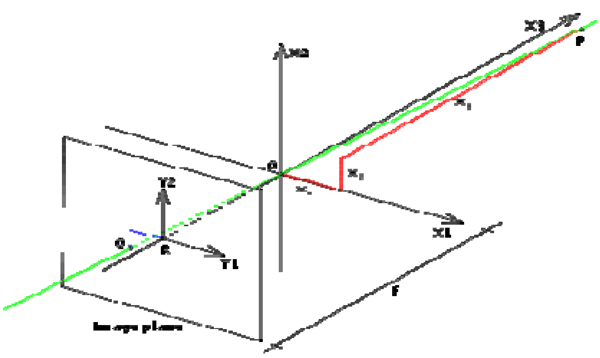

Fig. 3. Geometrical and mathematical projection of pinhole camera

Fig. 4 shows the geometry of a pinhole camera seen from x2 axis.

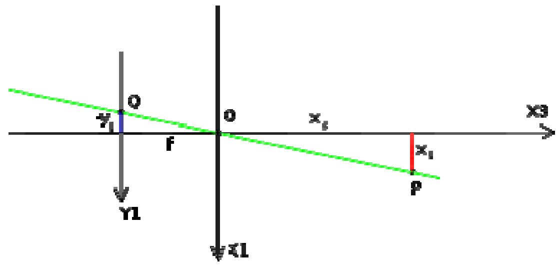

Fig. 4. The geometry of a pinhole camera as seen from the X2 axis

Since two triangles in the figure 4 are similar, it follows that;

$$y_1 = \left(-f \times \frac{x1}{x3}\right) \tag{1}$$

In the negative direction of x1 axis;

$$y_2 = \left(-f \times \frac{x2}{x3}\right) \tag{2}$$

$$\therefore \begin{pmatrix} y1 \\ y2 \end{pmatrix} = -\frac{f}{x3}\begin{pmatrix} x1 \\ x2 \end{pmatrix} \tag{3}$$

Equation (3) describes the relationship between the 3D coordinates (x1, x2,x3) of point P.

IV. Three Dimensional (3D) Structure of Vascular Skeleton

On the basis of the pinhole camera model described in section III, mathematical modeling for 3D structure of vascular skeleton have been introduced.

In general, the acquisition attitude of x-ray angiography is similar to the pinhole camera model and both are based on perspective projection [12]. The object in the x-ray image is enlarged and not inverted as compared to the pinhole camera image.

Fig. 5 shows imaging model of a monoplane angiography system. A projection process at a space point of the coronary artery tree is to be given as [12],

$$(xi,\ \ yi,\ \ zi)^T \rightarrow \left(SID\times\frac{Xi}{Zi}+Uc,\ \ SID\times\frac{Yi}{Zi}+Vc\right)^T = (Ui,\ \ Vi)^T \tag{4}$$

whereas $(Uc,\ \ Vc)^T$ are the coordinates of the principle point.

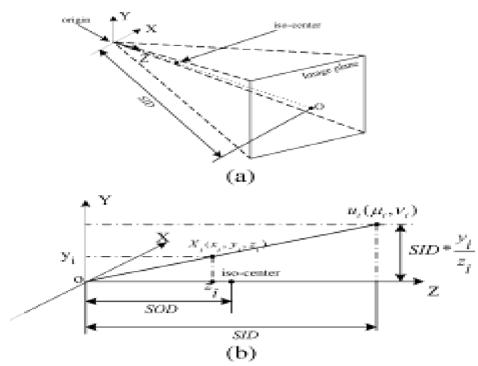

Fig. 5. Imaging model of a monoplane angiography system [12]

The intrinsic matrix of the angiographic system will be represented by K matrix.

$$K = \begin{bmatrix} \frac{SID}{\alpha u} & \frac{SID}{\alpha v} * S & Uc \\ & \frac{SID}{\alpha v} & Vc \\ & & 1 \end{bmatrix} \quad (5)$$

where αu and αv are the image pixel spacing in the u and v direction. Figure 6 shows geometric relationship between two angiographic views.

The projection of a space point Xi to the two views can be given as [12].

$$U_{1,i} = P_1 X_i \text{ and } U_{2,i} = P_2 X_i \quad (6)$$

where $U_{1,i}$ is the image coordinates and P_1 is the projection matrix of first view, similarly $U_{2,i}$ and P_2 are the parameters of the second view.

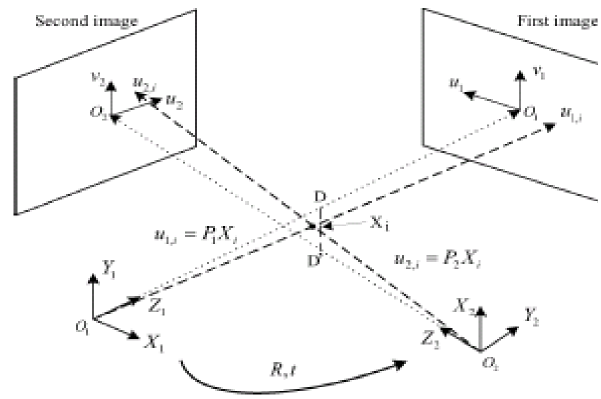

Fig. 6. Geometric relationship between two angiographic views

V. 3-D Construction of X-Ray Angiography Images From Two Projection

Our 3D reconstruction algorithm has need of correct detection of vessel boundaries. The observed intensity distribution along a line perpendicular to the vessel for a angle ϕ is given by following expression [14].

$$i(p) = f(p,\phi) * g(p) + b(p) + w(p) \quad (7)$$

where g(p) is the Gaussian point spread function with zero mean and standard deviation. b(p) is the background represents projection of bones and w(p) is the white Gaussian noise. The ideal projection of the vessel $f(p,\phi)$ is given by [14].

$$f_j(p_{j,}\phi_j) = \begin{cases} \frac{\mu_j f_{jcen}}{P_{j\max}} \sqrt{P_{j\max}^2 - (P_j - P_{jcen})} & for \quad P_{jcen} - P_{j\max} \le P_j \le P_{jcen} - P_{j\max} \\ 0 & Otherwise \end{cases}$$

where the index j = 1,2 and μ is the attenuation coefficient of contract agent.

$$Sj = \sqrt{c\cos^2\phi_j + a\sin^2\phi_j - \sin\phi_j \cos\phi_j}$$

$$P_{j\max} = 2S_j\sqrt{m}$$

$$f_{jcen} = 2/S_j$$

$$m = 4ac - b^2$$

And a, b, c are the parameters of elliptic cross-section. The parametric equation of elliptic cross-section is given by,

$$ax^2 + bxy + cy^2 = 1 \quad (8)$$

Figure 7, shows geometry of two-view projection of an elliptical cross-section.

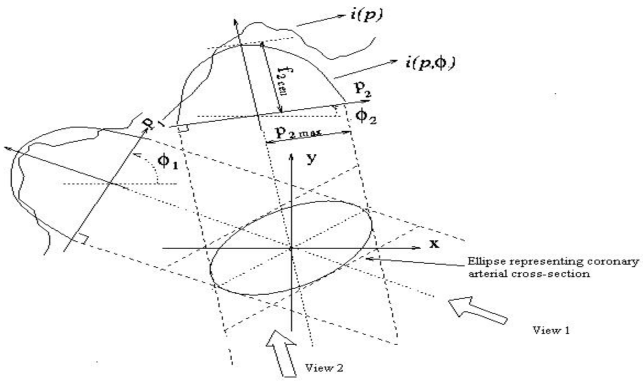

Fig. 7. Two-view projection geometry of an elliptic cross-section

The elliptical parameters a, b, and c are given by [15].

$$[c \quad a \quad b]^T = \frac{1}{4kl - n^2}[k \quad l \quad n]^T \quad (9)$$

where $$[k \quad l \quad n]^T = \frac{\frac{1}{4}(B^{-1} \quad A^{-1} \quad P)}{A}$$

$$P = \left[P_{1\max}^2 \quad P_{2\max}^2\right]^T$$

$$A = \begin{bmatrix} Cos2\phi_1 & 1 & Sin2\phi_1 \\ Cos2\phi_2 & 1 & Sin2\phi_2 \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & -1 & 0 \\ 1 & 1 & 0 \end{bmatrix}$$

Chronological steps for 3D reconstruction algorithm are depicted as below;

1) Image alignment: Since images are not alligned properly, alignment of two projection images is required before the application of the algorithm. This is attained by spotting branching points and stenosis points in images.
2) Magnification correction: Images from two views may not have the same magnification due to dissimilar distances from X-ray source to object and from object to image plane for every projection. Hence the magnification correction has to be carried out for every image by analytically from geometric parameters of the X-ray system.
3) Medial axis estimation: Centre point of a vessel cross-section is found by using geometrical relationship

between image planes and estimated P_{jcen} .

4) Calculating ellipse parameters: Substitute parameters P_{jmax} into equation (9) give up parameters a, b, c.
5) Finally, get 3D configuration of arterial segment by linking ellipses centered at the medial axis.

VI. EXPERIMENTAL RESULTS

Implementation has been carried out using MATLAB 2009 software on Intel® Atom processor N450 @ 1.66 Ghz, 2 GB RAM. Figure 8 gives the actual screen shots of the two 2D images. Figure 9 provides DICOM image information of two dimensional images. Figure 10 shows pre-processing stage of two angiographic images. Figure 11 gives parameter setting information of 3-D reconstruction process. Figure 12 shows actually reconstructed 3D view of angiographic images. This 3D reconstructed view can be seen in any angle by rotating the 3D image.

Applications: The main application of the article is in medical field.

1) Can be applied for the qualitative and quantitative analysis of coronary arterial disease such as atherosclerosis, aneurysm and arteriovenous malformation (AVM)
2) It can provide physicians with accurate inspection of the complex arterial network and quantitative assessment of vascular diseases in three dimensions.

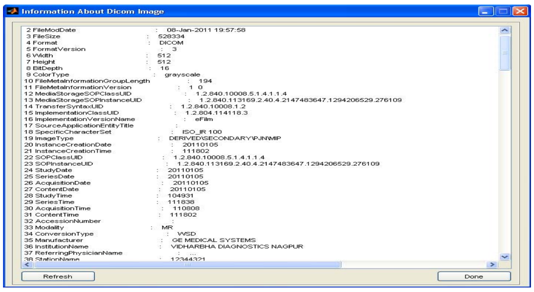

Fig. 8. Screen shows two 2D images.

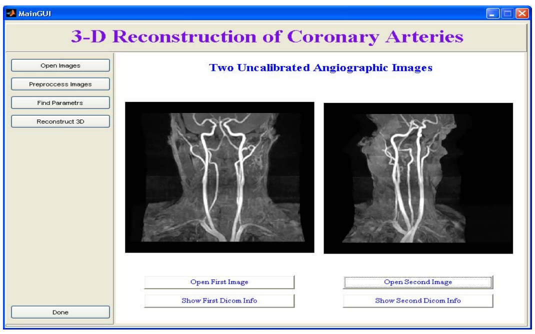

Fig. 9. DICOM image information of two dimensional images

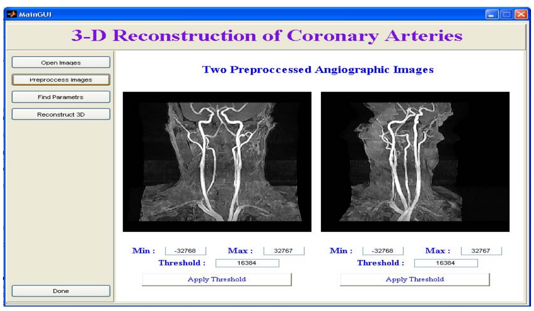

Fig. 10. Pre-processing stage of two angiographic images

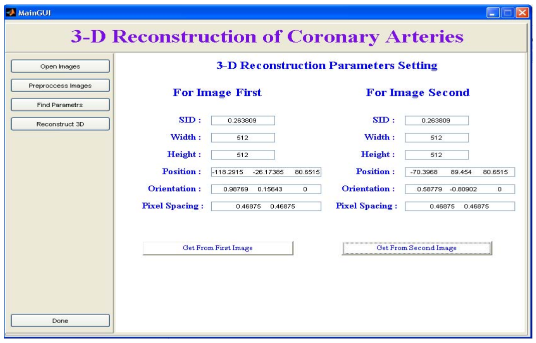

Fig. 11. Parameter setting information of 3-D reconstruction process.

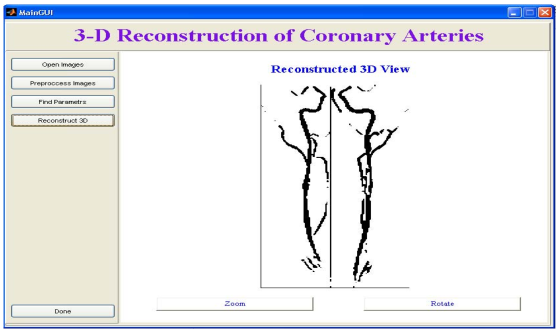

Fig. 12. Reconstructed 3D view of angiographic images

VII. CONCLUSION

We described a method for the 3D reconstruction of coronary artery. The performance of this method has been tested on arterial segments. The results designate the accuracy and utility of the described method. This method does not require precise information of attenuation coefficient of the contrast agent. It does not require exact estimation of standard deviation. In spite of excellent performance one of the described method one of the limitation we noticed that, overlapped projections have not been considered. The experimental results show that the method is effective and can accomplish accurate reconstruction results.

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Milindkumar Sarode received the B.E**.** degree in Computer Technology from the R.S.T.M. Nagpur University, Nagpur, India, M.E. degree in Computer Science and Engineering from the Swami Ramanand Teerth Marathwada University, Nanded, India and pursuing Ph.D degree in computer Science and Engineering from the S.G.B. Amravati University, Amravati, India. From 2002 to 2007, he was a lecturer at Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, India and an Assistant Professor since 2007 to 2011 and currently working as Associate Professor at the same institute in the department of Computer Science and Engineering. Till date he has presented and published 08 papers in national conferences in India, 32 papers in International conference in India and Abroad and 09 research papers in various International Journals. His research interest includes, digital image processing, medical imaging and related applications

Dr. Prashant R. Deshmukh received the B.E. degree in 1988, M.E. degree in 1997 and PhD in 2005. He is having 19 years teaching experience. He is working as a Professor and Head of the Computer Science and Engineering and Information Technology department at SIPNA's College of Engineering Amravati, India. He has published 23 papers in International conferences and journals in India and Abroad.
He received best teacher award for Maharashtra state, from Indian Society for Technical Education (ISTE), New Delhi in 2003. He has been honored by Eminent Engineer Award from Institution of Engineers (India) Amravati centre in 2004 and ISTE-Raja ram Bapu Patil National Award for promising Engineering Teacher for creative work done in Technical Education in 2007.