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# 3-D Reconstruction of Coronary Arteries from multiple different Angiographic views – A survey

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**ABSTRACT**
3D-Re-construction of the coronary artery vessel of the X-Ray angiography image is one of the useful technique that can effectively remedy the shortage angiographies imaging technique. Many publications can be found in the literature that present algorithms and techniques for coronary arteries reconstruction in angiograms. However, to the best of our knowledge, there is not any survey classify and do comprehensive comparative for all of them in one paper. In this paper, techniques have been divided into two main basic categories and propose a review for the geometric model. We studied all the papers in the geometric model and found there are two classifications: (1) based on methods, which has subdivided into (a) Epipolar Constraint Methods (ECM). (b) Deformable-Model-Based Methods (DMM). (2) Based on input data, which has also subdivided into (a) calibrated data. (b) un-calibrated data. Finally, we made three tables, the first table was to compare all techniques in each class against criteria like angiography types, the number of image view, Use phantom data, shape coronary artery output, whole tree output, and software implementation. The second table was to brief geometric model Methods description, Advantages, and Disadvantages. Moreover, the last table was to brief description of angiography types, Advantages, and Disadvantages.

***Key words:*** **Medical Image Processing, X-ray angiography images, 3-D Image Reconstruction, coronary artery.**

## 1. Introduction

An increasing number of doctor's reply on 3-D reconstruction to obtain coronary artery stenosis, a lot of research performed through the most recent Decade remains not prepared for the right time and in additionally not accessible in clinical routine. However, there are some techniques that already start do clinical research such as(Morris et al. 2013),(Campbell and Mahmud 2014),(Lansky and Pietras 2014),(Tu et al. 2014),(Ligthart et al. 2014),(Calmac et al. 2015). There is a significant restriction for the interpretation of the techniques to clinics. All the techniques should be accurate, at the same time, and robust. These three conditions are demonstrated truly difficult to meet. Hence, it is significant to choose precisely the best strategy for reconstruction coronary arteries. The imaging modality that utilized in this way is X-ray Angiography taken from Monoplane, Biplane or Rotational Angiography. Indeed, reconstruct coronary arteries by using this method can utilize greatly for visualizing stenosis for physicians during a real-time. Based on this ground, x-ray considered to stay the "golden standard" of all times within the medical imaging field. Several techniques and algorithms have been presented regards to coronary blood vessel reconstruction. In this paper, a review of algorithms and techniques, especially focusing on the coronary artery 3-D reconstruction from angiograms only. The review and different process which have to be done is proposed were explained and clearly showed the contribution for each phase in the reconstruction algorithms are presented in the literature(Goyal, Yang, and Prakashagrawal 2013). This paper, especially focusing on the 3-D coronary artery reconstruction techniques and algorithms in coronary angiogram only, showing early and recent papers, developments in this area and no such survey introduced based on our knowledge. The goal of this paper is to survey the 3-D coronary artery reconstruction in angiogram's methods, to give researchers a cataloged resource of the methods used for coronary artery reconstruction for well - arranged orientation for additional details; to investigate the disadvantages and advantages of the distinctive utilized methodologies.

Firstly, every reconstruction classes are defined and all the papers are briefly reviewed by relevant classes furthermore provide three table one of them show a comparison of all the algorithms surveyed. The comparison contains geometric model techniques, then the input type like monoplane, biplane, rotational angiography, the number of Image view, Use phantom data, output types such as a shape coronary artery, artery, whole tree and software implementation. The second table showed description, Advantages, and Disadvantages of the geometric models. And the third table showed a description of angiography types, Advantages, and Disadvantages.

This paper is organized in five sections; Section two represent the categorization of 3-D coronary artery re-construction in angiograms from 2D X-ray Angiography images. A short summary of papers in applicable class is projected in Section 3. The comparison table and discussion are given in section 4. Lastly, the conclusion and future works are delineated in Section 5.

## 2. Categorization of 3-d coronary artery reconstruction in angiograms

Researchers have done a lot of work on 3D modeling of coronary arteries. 3-D modeling from 2D angiography images has gained high attention among them. A variation of techniques has been expanded for the 3-D reconstruction of coronary artery angiograms from 2 or additional views. These techniques are often classified into 2 main classifications, every established with a different view: firstly, the techniques can be categorized based on the type of angiography device utilize for reconstruction, which can be a monoplane system, a biplane system, or a rotational system. More details presented in the literature (Goyal, Yang, and Prakashagrawal 2013) (Yang et al. 2009). Among them, the most common instrument used is the monoplane angiography system for coronary intervention treatment, furthermore, the techniques deployed on a monoplane system could also be applied to a biplane and rotational angiography systems. The next category of techniques for 3-D re-construction is based on the geometry models applied for re-construction, this also can be divided into two classifies as: (1) based on the method used which is: Epipolar Constraint Methods and deformable-model-based Methods. Or (2) based on the input data which is: calibrated and un-calibrated input data. As shown in figure (1) below.

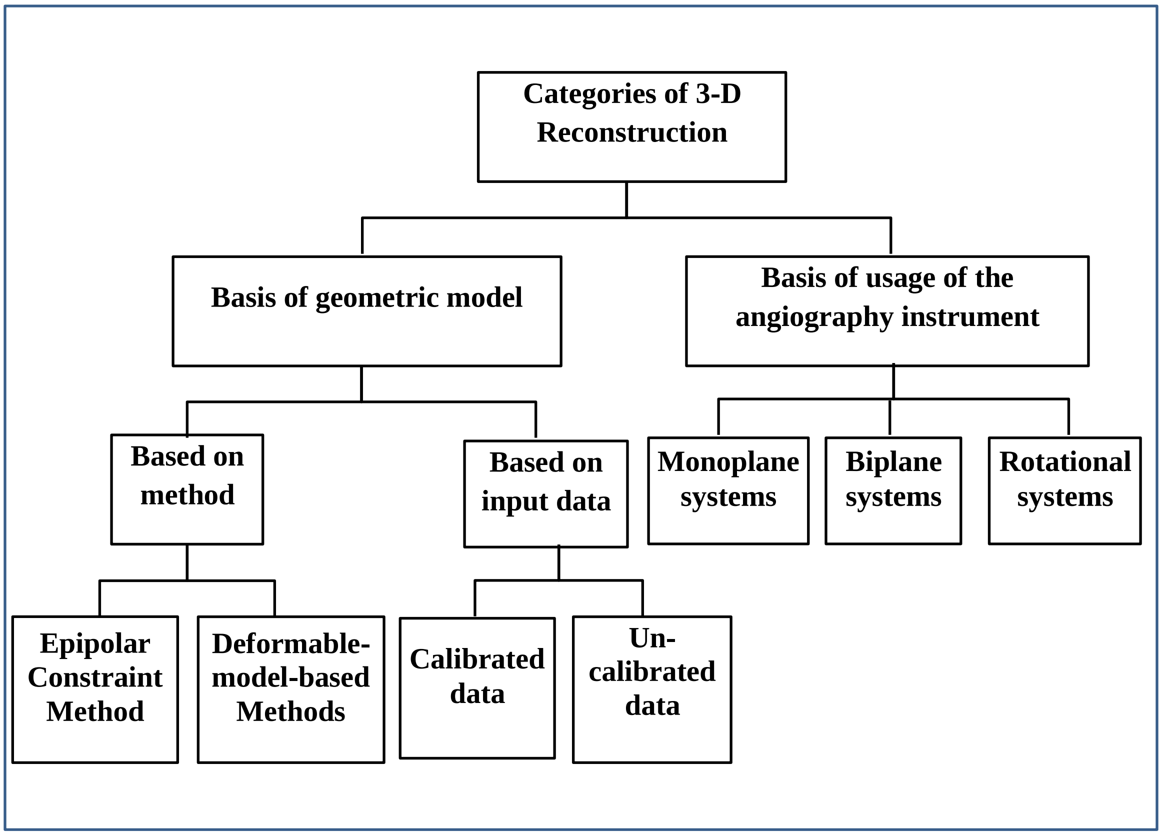


Fig. 1. Categorization of 3-D coronary artery reconstruction in angiograms

## 3. 3-D re-construction on the basis of the geometry models

Many geometry model reconstruction methodologies have been suggested to visualize coronary arteries in angiograms. These geometry models reconstruction techniques have a variant way to classify such as: based on the method used such as the Epipolar Constraint Methods and the deformable-model-based Methods. Or based on the input data, which is: calibrated and un-calibrated data approximately similar mentioned in (Cong et al. 2015). At this point, we need to suggest a classification to the coronary artery reconstruction technique in 2D angiograms which have implied the geometry model techniques. Thus, numerous algorithms in coronary arteries re-construction in methods are studied in which utilized the geometric model techniques and classified each one into two classifications as following.

## 3.1 **The first class of 3d reconstruction based on methods**

### 3.1.1 Epipolar constraint methods (ECM)

The epipolar geometry concept is fundamental to determine the extrinsic parameters for 3D reconstruction (Hartley, R., & Zisserman 2003). In 3D re-construction, an intrinsic projective geometry between two images at the same scene was taken from two views in different angles, can be win, which is called as the Epipolar geometry. In other words, Epipolar geometry lets us know how the two views are related to one another. The Epipolar geometry does not determine the scene structure. It determined by the internal parameters of the cameras and their relative posture (Hartley, R., & Zisserman 2003). To build a corresponding link among angiography images, The epipolar constraint technique usually uses epipolar geometry constraint, then by triangulating different correspondences established by the geometric parameters of the corresponding angiograms, we can settle 3-D vasculatures (Bousse et al. 2009) (Liao et al. 2010). A movement advantage strategy was presented in (Bousse et al. 2009) to deal with the corresponding inaccuracy among different projections. The correspondence estimation outcomes effect strictly to the accuracy of re-construction. Nevertheless, one basic issue with this technique is the probability of multiple intersection points among the vascular structures and the epipolar lines, which leads to an effort to find the real correspondences. particularly when the epipolar lines parallel with the vessel segments or vessel segments are overlapping (Zhang, Deriche, and Faugeras 2004). therefore, the accuracy of the reconstruction is resolute by the epipolar geometry accuracy resolute. A technique presented by Andriotis et al. (Andriotis et al. 2008) that gathering image improvement, edge detection automatically, an iterative strategy to reconstruct the center line of the artery and reconstruction of the width of the vessel by the respect the foreshortening impacts. Yang et al. 2009 presented a new method, depends on the model of a pinhole camera and current optimization methods, to non-linearly optimizing and re-fining the 3-D vessel structure thinning consider the treatment of un-calibration caused from the movement of the table and issues connected with the movements of the patient's body. The researchers highlighted that the extraction of the corresponding point is semi-automatic yet also, matching theirs is truly a troublesome issue. (Yang et al. 2009). Sarode et al. (Sarode and Deshmukh 2011) model every cross sections in a pinhole camera model as ellipses discounting overlapping projections. Wu et al. (Wu et al. 2011) develop a method for the calculating of the correspondences from multiple view projections. Cardenes et al (Cardenes et al. 2012) proposed a strategy for the coronary arteries 3-D reconstruction from a 3-D coronary artery, utilizing correspondences among center-line branches and carrying out a pack ray matching to find the perfect 3-D directions of the vessels. Goyal et al (Goyal and Agrawal 2013) integrated the epipolar constraint and curve matching to compute the correspondences in two various angiographic images. Iskurt et al. (Iskurt, Becerikli, and Mahmutyazicioglu 2013) designed a completely automatic system which content: preprocessing, segmentation, matching and reconstruction phases for that reason. This technique has some advantages like branch by branch reconstruction. Also, evades the incorrect overlapping branches in contrast protection the reconstruction mistakes at adequate levels. Auricchio et al (Auricchio et al. 2014) basic structure to create 3-D coronary bifurcations meshes from a couple of planar angiographic images acquired by X-ray angiography. Montion et al(Montin et al. 2016) proposed a 3D reconstruction method of an angiographic vessel centerline based on heuristic optimization of the view homogeneous coordinates system scaling factor. Mufit et al(Cetin and Iskurt 2016) proposed a novel and the completely automatic system is designed that covers preprocessing, segmentation, matching and reconstruction.

### 3.1.2 Deformable-model-based methods (DMM)

Deformable models are techniques where models are deformed to best fit the object. In the 1980s, An initially Terzopoulos et al. who's present the deformable model (Terzopoulos and Fleischer 1988), (D. TERZOPOULOS ET.al, n.d.) and was first utilized to achieve flexible deformation, calculating shape model, vessel extracting, and movement containing. deformable-model-based optimization approaches are an alternative possible solution to estimate the re-construction. Defining the combination of external and internal forces, the deformable curve is regularly developed to the goal vessel segment. This technique has been extensively explored for vascular structure re-construction. furthermore; it does not calculate the corresponding calculation. Molina et al. (Molina et al. 1998) initially proposed the snake model designed for reconstruction vascular structure. At first, a few numeral of correspondences were constructed into two angiography images via using the epipolar constraint. Then through B-Spline interpolation, the first snake after that was ordered via the correspondences. Then snake curve already advanced in space via minimizing the distance between the corresponding image data and the projection to correct its projections in images. Cañero et al. (Cañero et al. 2002) improve the 3D biplane snake behavior to reconstruct. the main branches of the coronary structure, for resolving the issues related to corresponding points matching. Zheng et al. (Zheng, Meiying, and Jian 2010) propose a semi-automatic strategy for sequencing reconstructing. coronary artery thinning from a couple of X-ray coronary angiography series based on snake model to solve the shifting and shrinkage issues that can be affected by balancing the internal and external energies through optimization by combining the intrinsic properties of the curve and prior information of the coronary arteries. In this strategy, there is a need to establish the essential starting points in the 2-D image of the vascular pack, a few intermediate points and also the end points. (Goyal and Agrawal 2013)

One basic issue for these techniques (deformable model) is the probably largest reconstruction errors in with fewer curvatures for vascular segments since the non-strict corresponding points are usually utilized to construct the spatial point via triangulating the correspondences. Furthermore, the curve deformation is straight set by the energy among the target and also the source vessels; in this way, the geometry of the projection isn't completely used. In general, the vasculatures in 3-D space can be iteratively improved the deformable model - based techniques based on the projection forces of every vessel segment in 2D angiographic images, that may be set as the external force projective iteration model (EFPIM) based techniques. In order to rectify the problem of non-strict matching of (EFPIM) based techniques, Cong et.al presented a new external force back-projective composition model (EFBPCM) for vasculature deforming, also enhancing the reconstruct. precision to rectify the re-construction issue for two angiographic images (Yang et al. 2014) (Cong et al. 2013). Cong et.al (Cong et al. 2015) extend the previous (EFBPCM) suggested and combined in the deformable model structure for the 3D reconstruction. of coronary arteries taken from several angiograms to various angiography images.

The advantage of this solution is that calculation of correspondence of each feature point on the vascular structure isn't essential, however the images need to be taken at the similar cardiac cycle to avoid elastic warp between varied parts of the vasculature. (Goyal, Yang, and Prakashagrawal 2013)

## 3.2 **The second class of 3d reconstruction based on input data**

### 3.2.1 Calibrated input data

During the imaging, Calibration procedure might be performed (Wiesent et al. 2000) or prior (Fahrig and Holdsworth 2000). In calibration during imaging the patient, the visibility of the patient information would be reducing the patient information because the calibration information is imaged on the same screen. Likewise, the imaging calibration needs to be done every time. Despite the fact that calibration before imaging doesn't have an affect the information recording procedure, it ought to confirm that's calibrated repeated frequently (Movassaghi et al. 2004). In calibration methods, to locate the intrinsic parameters of the equipment, independent steps are performed. By using the pinhole camera model, we can calculate The extrinsic parameters and correspondences. Then we can reconstruct the structure of the vessels by triangulating the correspondences. Algorithms work with this class are in the articles: (Cañero et al. 2002), (Andriotis et al. 2008), (Zheng, Meiying, and Jian 2010), (Wu et al. 2011).

### 3.2.2 Uncalibrated input data

In the Uncalibrated procedure, semi-automatically determined a few number of correspondences in the 2 images via straight assessment of the projections. ordinarily, noticeable features include bifurcation points and end points of the vessel are selected. At that point, a selection of correspondences is utilized to perfection the projection geometry and the structure of the vessels. Algorithms work with this class are to the articles: (Yang et al. 2014; Sarode and

Deshmukh 2011)

## 4. Summary

The summarized of aforementioned research are shown in Table 1 based on the geometric model methods utilized for coronary artery reconstruction in angiograms. column three shows the type of approach employed to reconstruct coronary arteries. The column of the input type illustrates the types of the input image, like angiography types (monoplane, biplane, rotational angiography) and a number of image views. The calibrate column reveals if the method is calibrated or un-calibrated, the column of the output type shows that reconstruction object is a part of coronary arteries (or whole tree). The next column is user interaction assign which the reconstruction is manually or fully automatic. The phantom data column shows the implementation done using a phantom model or not. And the last column indicates the software implementing which used in each paper. Table 2 below summarizes the advantages and limitation of each methodology. Table 3 below shows the types of angiography instrument used for reconstruction and its advantages and disadvantages for each of them.

## 5. Conclusions

This paper was trying to cover both recent and early literature which just focuses on coronary artery 3-D reconstruction by two or more angiography images. In this phase, our goal was to classify all the studies in geometric model methods only. We planned to give the physician a framework for the current research. Greatest works on coronary arteries 3D reconstruction are constructed on stereo vision algorithms (epipolar geometry). The accuracy of the re-construction remains the most concerned issue in the 3-D re-construction of coronary arteries. Recommendation for future works includes improving the accuracy and the speed of image re-construction for the Uncalibrated method in angiography images.

Table 1: 3-D Reconstruction Algorithms of Coronary

| Algorithm | Year | Category | Input type | | | | | Using Phantom / real data | Output type | | | Automatic | User interaction | SW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Angiography types | | | | | | Shape type | | | | | |
| | | | Mono p. | Bi p. | Rot p. | NO. Image view (projection) | Calibrate | | 3d mesh | SV | Whole tree | | | |
| **Canero et al** | 2002 | DMM | - | Yes | - | 2 | Yes | Both | No | No | No | No | No | NM |
| **Andriotis et al** | 2008 | ECM | Yes | - | - | 2 | Yes | Both | NM | Yes | Yes | No | Yes | NM |
| **Jian Yang et al** | 2009 | ECM | Yes | - | - | 2 | No | Both | NM | NM | NM | No | NM | C++ |
| **Zheng.Sun et al** | 2010 | DMM | Yes | - | - | 2 | Yes | Real | NM | Yes | No | Semi-automatic | Yes | C++/ open GL |
| **Sarode et al** | 2011 | ECM | Yes | - | - | 2 | No | Real | NM | NM | NM | No | Yes | Matlab |
| **Wu et al.** | 2011 | ECM | - | - | Yes | Multiple | Yes | Real | NM | NM | No | No | NM | NM |
| **Cordons et al** | 2012 | ECM | - | - | Yes | 2 | Yes | Both | No | NM | No | No | NM | NM |
| **Goyal et al** | 2013 | ECM | Yes | - | - | 2 | Yes | Both | No | NM | No | No | NM | C++ |
| **Iskurt et al** | 2013 | ECM | Yes | - | - | NM | Yes | Both | No | NM | No | Yes | No | Matlab |
| **Auricchio et al** | 2014 | ECM | Yes | - | - | 2 | Yes | Both | Yes | No | No | No | Yes | Matlab |
| **Cong et al** | 2015 | DMM | - | - | Yes | Multiple | Yes | Both | No | No | No | No | NM | C++ |
| **Montion et al** | 2016 | ECM | Yes | - | - | Multiple | Yes | phantom | No | Yes | No | No | No | Matlab |
| **Mufit et al** | 2016 | ECM | Yes | - | - | 2 | Yes | Both | Yes | No | No | Yes | No | Matlab |

A key to table

Mono p. :Monoplane
Bi p. :Biplane
Rot A.: Rotational Angiography (X-Ray)

NM :Not mentioned
Deformable-model method(DMM)
Epipolar Constraint method (ECM)

SV : Surface visualization
SW : Soft Ware Implemented

**Table 2:** A brief comparison of the coronary vessel 3d reconstruction *based on methods* in the x-ray angiogram: description, advantages, and limitation of methodologies

| Reconstruction technique | Method description | Advantages | Disadvantages |
|---|---|---|---|
| Epipolar Constraint Methods (ECM) | First, the centerline is segmented in the two views. The corresponding points may be found within the different views using epipolar geometry and after that, the 3D reconstruction can be computed. The vessel boundaries are computed by using the radius in 2D. | The Epipolar geometry does not depend on the scene structure. | - Multiple possible crossing points between the vascular structures and the epipolar line, that cases struggle to find the actual correspondences, particularly in the case of a parallel vessel with the epipolar lines or are overlapping vessel segments.<br>- Not applicable on-line throughout the acquisition as a result of the long task of matching corresponding points on every couple of views. |
| DEFORMABLE MODEL BASED METHODS (DMM) | by defining external and internal forces in a 2d image, the deformable curve is regularly evolved toward the target segment of the vascular vessel. The vascular structure in three D area adapts its' structure to a stable representation, that has minimum projection errors altogether projections. | - there is no require for correspondence calculation to every feature point on the vascular structure. | - vascular segments reconstruction with small curvatures can be with a large Possible error |

Table 3. A brief comparison of the coronary vessel 3d reconstruction based on the type of angiographic device used for reconstruction in the x-ray angiogram: description, advantages, and limitation of methodologies

| Angiography types | Types description | Advantages | Disadvantages |
|---|---|---|---|
| Monoplane | a coronary artery with One view is concentrated at a specific time | -Still widely used in medical imaging and it's considered to stay the "golden standard"<br>-Cardiologist gets the Angiography image online | -Provides one angiogram from one angle<br>-Overlapping and foreshortening within the image |
| Biplane | stationary views with Two or more predefined, around the patient at different angulations for both left and right coronary arteries are taken in the time | Biplane X-ray angiograms deliver twice the information with a single contrast injection, and both images are at the same time | -Not available in every clinic |
| Rotational Angiography | -Obtained series of X-Ray images.<br>- by rotating the C-arm around the patient can be acquired Volume of data. | Less reliance on operator's visual skills, Produces 3D visual effect, Standardized imaging platform, more perspectives of the coronary tree. | No quantification of 3D features, a larger field-of-view required with current image intensifier technology, Acquisition protocols may be different for specific needs Less radiation, Determining optimal views still operator-dependent, |

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