Review Article

A REVIEW ON IMAGE PROCESSING BASED OPTIMAL CATHETER SELECTION IN CORONARY ANGIOGRAPHY

Sami Ur Rahman[a], Adnan Khalil, Fakhre Alam

Abstract:
Image processing based optimal catheter selection is a newly developed approach for coronary artery angiography. In image processing based approach, an optimal catheter is selected (before intervention) on the basis of internal anatomy of the patient's coronary artery. This advanced method of optimal catheter selection provides extremely valuable information on coronary artery structures, and reduces the operating time and risks of testing different catheters on a patient. The aim of this paper is to describe and evaluate image processing based optimal catheter selection in coronary angiography. This paper also presents the main limitations of image processing based optimal catheter selection approach, and provides possible solutions and suggestions for future research.

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INTRODUCTION

Quantification of the different parameters from the image data is very important for planning and diagnosis. In coronary artery angiography [1], the accurate estimation of diameter of the aorta and coronary arteries, curvature of the aorta, and curve angles of the coronary arteries are essential. These measurements are also important for selecting an optimal catheter. The traditional method of coronary artery angiography is based on trial and error i.e. the cardiologist select patient specific catheter by trying several catheters on patient. This method is time consuming and the chances of internal artery injuries are high.

Image processing based coronary artery angiography is a new method for optimal catheter selection based on patient's image data [2,3,4]. The method is acquired prior to the intervention and extracts data from patient's arteries. The only requirement for the image processing based angiography is to have patients MR/CT data before starting angiography. Image processing based methods reduces the chances of injuries in the internal artery and minimizes operation time. These advanced methods extracts geometrical information from the internal anatomy of the heart and select an optimal catheter (similar to patient anatomy).

In image processing based angiography, projection plane play an important role in computing parameters from the image data. The existing image processing based optimal catheter selection methods extract coronary arteries curve from the patient image data and project the coronary artery curve in the 2D plane. The reduction of 3D curve of coronary arteries into 2D affects the accuracy of computed parameters. The projection of 3 D curve on 2D plane greatly affects the accuracy of computed parameters. It is due to the missing of appropriate plane in the projection. Therefore, the existing image processing based catheter selection methods need further improvement in estimating the projection plane.

The objective of this review paper can be summarized as: a) to present the general concepts about major causes of hearts diseases and the available methods of coronary artery angiography. The purpose is to provide an idea to novice researchers in the field. b) to identify and present some of the most important issues in catheter selection c) to describe features of extraction method for optimal catheter selection, the existing catheter selection models and their limitations d) To present solutions, techniques and research guidelines that might help in coping with some of the issues and in developing more advanced optimal catheter selection methods for coronary artery angiography.

This review is divided into four sections: Section 1 which presents general concepts and techniques related to coronary artery angiography. Section 2 describes image processing based angiography and its different techniques. Section 3 presents issues in image processing based optimal catheter selection and its possible solutions. Concluding remarks are presented in Section 4.

[a]University of Malakand
Chakdara, Khyber Pakhtunkhwa, Pakistan,
* Corresponding author:
Email:fakhre.uom@gmail.com

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1. CORONARY ARTERY ANGIOGRAPHY:

In the last two to three decades, heart disease is one of the major causes of death and disability in both developed and developing countries. The annual death ratio of people around the world from heart disease is more than other causes. Statistics show that with the rapid growth of world population from 1990 to 2013, the number of deaths due to heart disease also increased from 12.3 million to 17.3 million, which is an increase of 41%[5].

In atherosclerosis, atheromatous plaques and fatty materials are developed inside the blood vessels[6]. Atherosclerosis creates irregularity in blood vessels, narrows down the lumen, which greatly affects the supply of blood inside coronary artery, and causes most heart attacks and strokes as shown in Figure 1. Plaques and fatty material not only cause the blockage of blood flow but also the affect supply of oxygen to the heart muscles. Such types of blockages causes death to the heart tissues as shown in the Figure with purple area.

Coronary artery angiography is the most common type of invasive heart catheterization [7,8] procedure in which radio-contrast is injected into the blood vessels of the heart under X-ray guidance. The purpose is to diagnose and treat possible heart and blood vessel obstruction. In coronary angiography, a catheter is inserted through an artery from the arm or groin of the patient and is moved it up into the heart. The orientation and proper position of the catheter is adjusted with the help of a series of X-ray images, which provide a detailed internal view of blood vessels. After the insertion and proper placement of the catheter, a contrast material is also injected into the catheter, which helps to highlight any obstruction in blood flow. Today, coronary artery angiography is the essential diagnostic procedure for the determination and treatment of heart diseases. Figure 2 shows the process of cardiac catheterization.

In this medical imaging procedure, the arteries, veins and the heart chambers are visualized to find out any blockage in the coronary arteries. Although, a lot of advanced techniques have been developed recently for coronary angiography but still cardiologist faces problems for selecting a suitable catheter for given patients. This is due to the anatomical variation of the aorta and coronary arteries in different individuals. While choosing a catheter for a particular patient, cardiologist test several catheters on a patient till he finds an optimal one. The selection of optimal catheter according to the internal structure of aorta and coronary artery of a patient is not only a time consuming process but can also increases the chances of puncturing the artery if it is not matched with internal anatomy. Furthermore, infection, reaction to contrast dye, abnormal heart rhythm and a chance of cancer from excessive exposure to radiation are some other problems in coronary angiography. Therefore, the cardiologist will efficiently perform coronary angiography and the patient will face minimum problems if optimal catheter is selected in advance.

To select optimal catheter before starting coronary artery angiography, an image processing based method was developed by Rahman et al.[3] The method uses the MR or CT image data of specific patients to extract geometric parameters from the coronary artery and aorta. On the bases of extracted parameters, an optimal catheter for the patient is selected.

2. IMAGE PROCESSING BASED ANGIOGRAPHY:

Image processing based catheter selection[10] is

Figure 1: Plaque buildup in the coronary artery that causes heart attacks and strokes

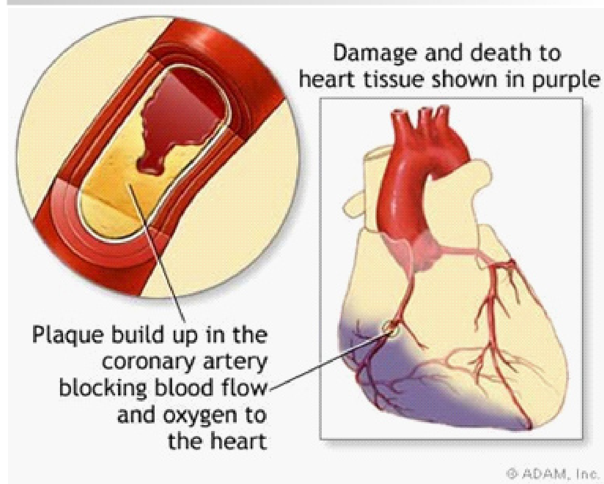
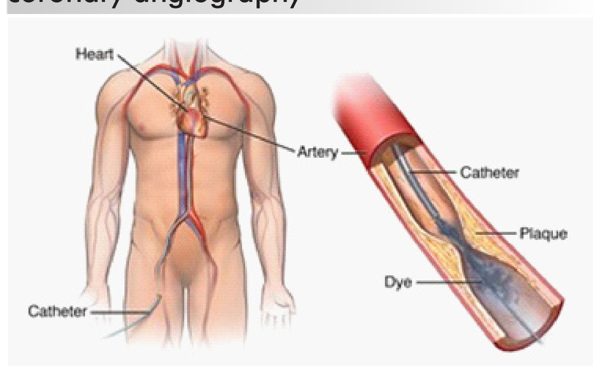


Figure 2: Cardiac catheterization or coronary angiography



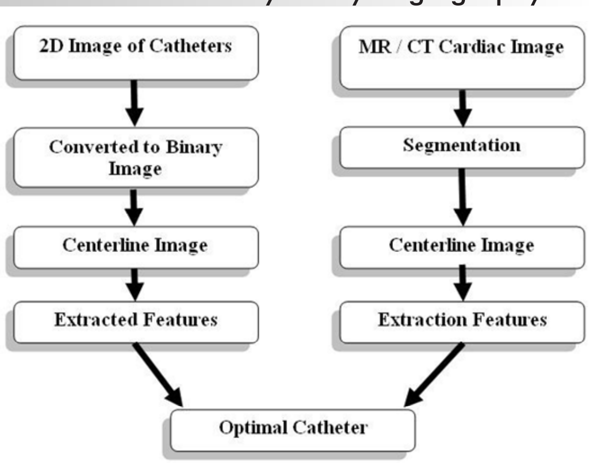
a new technique for catheter selection based on patients image data. This technique is acquired prior to the intervention and extracts data from patients arteries. The only requirement for this system is to have patients MR/CT data before starting angiography. The required arteries, i.e., the aorta and coronary arteries are segmented from these image data. In the next step, some clinically important geometric parameters are computed from the segmented images. At the same time, clinically important geometric parameters are computed from all the available catheters. Based on these parameters from the patient image data and parameters from the catheters, optimal catheters are suggested for the patient. Figure 3 shows the pipeline of the image processing based catheter selection procedure. The Figure has two different processing pipelines i.e. the left pipeline and the right pipeline. The left processing pipeline shows the method of features extraction from the considered catheters while the right one shows the method of feature extraction from the patient MR/CT image data.

2.1. Computing Geometrical Parameters From Catheters

Geometrical parameter estimation from catheter is a simple procedure[11]. This method takes images of catheters and extracts their centerlines. After the centerline extraction from each catheter, catheter curve angle and curve length are extracted from the centerline image. Angle and length of catheter curve are important because these parameters are compared with the parameters of the patient image data.

2.2. Computing Geometrical Parameters from Patient Image Data

Figure 3: Processing pipeline of features extraction from catheter and MR/CT image data to select patient specific optimal catheter for coronary artery angiography



The following steps are used for computing geometrical parameters from patient image data. After the computation of all these steps, patient specific optimal catheter is selected.

I. Patient MR/CT image data

The first step of image processing based optimal catheter selection is to get the MR/CT image of the patient. This is the only requirements of the method to select a patient specific optimal catheter.

II. Aorta and Coronary Artery Segmentation

The aorta and coronary artery segmentation is the second step in the image processing based optimal catheter selection. Parameters are computed from segmented aorta and coronary artery of the patient image. Therefore, the segmentation of the aorta and coronary artery is performed.

III. Centerline Extraction

In the existing method, centerline image is used to extract the parameters from the MR/CT image of the patient. The parameters that are extracted from the patient image are the diameter of the coronary artery and these parameters are calculated from centerline and segmented image. The centerline image is also used to find the coronary arteries curve angle and length. These two geometrical parameters are the most important parameters in optimal catheter selection model.

IV. Feature Extraction

After the centerline image extraction, the next step is to extract features from the centerline image and segmented image. To extract the coronary artery curve angle and length, the existing method follows centerline image. As a result, coronary artery curve length and angle are obtained. In the last step, the existing method creates a 2D projection plane, projects the coronary artery curve on the2D plane, and after the projection, the specified geometric parameters are extracted.

V. Optimal Catheter Selection

Optimal catheter selection is the last step of the existing method for coronary artery angiography as shown in the Figure 3. In this step, the extracted parameters from catheter and image data are compared and an optimal catheter for a patient is suggested. The comparison between extracted parameters from catheter and image data is performed quantitatively as shown in equation[14].

Where I is the ith catheter and the value of

$$OC = \arg\min_{i} \{CC_i\} \quad (1)$$

$$CC_i = x\sqrt{\left(\frac{1}{N_1}((CCA)_i - CACA)\right)^2} + x\sqrt{\left(\frac{1}{N_1}((CCL)_i - CACL)\right)^2} \quad (2)$$

CCi is shown in equation 2. In equation 2, N1 andN2 are the normalization factors and x and y are weights assigned to each expression of the equation. In this equation, CCA is catheter curve angle, CACA is coronary artery curve angle, CCL is catheter curve length and CACl is coronary artery curve length.

3. LIMITATIONS OF IMAGE PROCESSING BASED OPTIMAL CATHETER SELECTION:

The traditional methods of catheter selection (also called trial and error based) are time consuming and risky due to variations in the aorta and coronary arteries in different humans. In the traditional methods, it is not possible to use a common catheter for all patients. The cardiologists test different types of catheters on patient and select an optimal one. It will be more helpful for the cardiologists if they select an optimal catheter (according to patient anatomy) prior to coronary artery angiography. Image processing based patient specific catheter selection is a new and emerging field in the area which can overcome all these issues. The selection of patient specific catheter before coronary angiography not only reduces the exposure time to radiation but also the possible risk of artery punctures and internal bleeding.

Currently, limited work is available on this challenging area of research e.g. Rahman et al. [3,4]. In the existing work, two approaches are available for the selection of optimal catheter i.e. a) Patient specific optimal catheter selection for the left coronary artery and b) Patient specific optimal catheter selection for the right coronary artery. These approaches provide helps to cardiologists to select the catheter according to the patient's anatomy. In these approaches, the selection of optimal catheter is based on the information about the geometry of the patient's aorta and coronary artery, and geometrical information from the available catheters. We have evaluated all the geometric parameters for the selection of optimal catheter and identify some issues and limitations in the already developed approaches. These issues and limitations are presented along with their possible solution, which we think will be helpful for the development of new advance image processing based optimal catheter selection methods. These issues and their possible solutions include:

a) In the existing methods, the extracted curve of coronary arteries is projected on 2D plane. This is one of the main problems for accurate feature extraction. In the patient image data, there is high possibility to generate several planes, which can be used for the projection. The calculated geometrical parameter values are different for each projection plane and there is no methodology in the existing method, which provides information for the accurate projection plane. The development of new methodology, which calculates the accuracy of projection plane will cope the problem of accuracy in the existing methods. Moreover, calculating parameters in 3D will also solve the problem of projection plane.

b) In the existing methods, the catheter selection model is based on weighted variables and the values of weighted variables create problems in the optimal catheter selection. Changing the weighted variables, the existing model selects a different choice of catheter for a specific patient. The inclusion of a new parameter i.e. ostium position will remove the weighted variables from the existing model due which a more suitable catheter will be selected.

c) The existing methods also suffer from image resolution. The method fixes the aorta and coronary artery curve in 30 slices, therefore, changing the resolution of the image also changes the size of aorta and coronary artery curve. In order to resolve this issue, there is a need to introduce a new step in the existing method which precisely extract the aorta and coronary artery curve.

d) The existing methods extract the aorta and coronary artery curve by following the centerline image using several conditions which is time consuming processes. The development of new advanced method which directly extracts the aorta and coronary artery curve without following the centerline image will minimize the processing time.

4. CONCLUSION:

Image processing based optimal catheter selection is a recently developed method for coronary artery angiography and a limited work is available on it. In this paper, we have presented a review on the existing method for optimal catheter selection in coronary artery angiography. Catheter selection problems during coronary artery angiography and the available approaches on image processing based optimal catheter selection are highlighted in extreme. Although, tremendous efforts have been done for the selection of image processing based optimal catheter in coronary angiography. However, the existing method faces some limitations, which need further improvement. In this review paper, all the limitations in the existing method i.e. projection on 2D plane, the presence of weighted variables, the problems of image resolution and the extraction of curve by following the centerline are presented and their possible solutions are suggested. The inclusion of new techniques in the existing approaches of image processing based optimal catheter selection will further improve the performance and accuracy.

Author's Contribution

SUR: designed the idea and interpreted the data. AK: performed the experimental evalution and tested the results. FA: wrote the paper and made corrective measures.

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