GUIDEWIRE AND CATHETER SIMULATION FOR VIRTUAL CORONARY ANGIOGRAPHY

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Abstract

Coronary angiography is a common medical procedure for diagnosis of heart problems. With catheterization, a dye is injected into coronary arteries. Through X-ray images, doctors can find any abnormalities of coronary arteries or any blockage in the coronary arteries. The procedure requires catheter and guidewire manipulation skills. Computer simulation has been adopted as a tool of training those skills for coronary angiography. Spline is a mathematical function of curve and it has been used for tracking a guidewire in x-ray images. In this paper, a guidewire and a catheter were simulated in the aorta using spline. With B-Spline, a guidewire in aorta is simulated. Catmull-Rom spline is adopted to simulate the movements of the catheter and the guidewire in aorta. As the simulation is now being used in training doctors for coronary angiography, this method of spline for the simulation of catheter and guidewire can be adopted to train the manipulation skills of the catheter and the guidewire.

Keywords: Coronary Angiography. Simulation. Medical Education. Catheter. Guidewire. Spline.

1. Introduction

There are challenges for tracking a guidewire in fluoroscopy. Guidewires are thin and consequently have low visibility in fluoroscopic images. A low dose of radiation in imaging makes even lower the visibility. Noisy images poses a challenge to track a guidewire. More challenges come from the shape deformation of a guidewire due to a patients' breathing and cardiac motions. Other wire-like structures make it difficult tracking a guidewire such as guiding catheters and ribs. Researches have been done for tracking a guidewire using spline.

A guidewire model is introduced that consists of three parts: a catheter tip, a guidewire tip and a guidewire body [1]. The guidewire was modelled mathematically with a spline model. It used cubic spline functions. This paper reported the spline representation reduced significantly the complexity of guidewire tracking. Another spline use of tracking a guidewire was for endovascular interventions [2]. The paper presented a method to extract and track the position of a guidewire during endovascular interventions under X-ray fluoroscopy. In the paper, the guidewire was represented with a spline parameterization which was a third order B-spline curve. A deformable B-spline tube model was used to represent the shape of a catheter and guidewire[3]. In this paper, instead of control points, knots were modified for B-spline representation. During the catheterization, the catheter moves along the guidewire. Consequently, the overall shape of guidewire and catheter changes because of the changes in mechanical properties such as the bending stiffness and bending moment. Considering these, a composite model was proposed to simulate a combination of a catheter and a guidewire[4].

Base on the literatures, B-spline curve was chosen to represent the guidewire in aorta. But, the combination of a catheter and a guidewire behaves differently than a catheter or a guidewire alone. In order to simulate the combination of catheter and guidewire, Catmull-Rom spline was chosen because of more local control than B-spline. The property of Catmull-Rom spline passing through control points gives more flexibility and control over the shape of a curve.

The standard basis function of a B-spline curve of degree k-1 can be represented as:

$$C(u) = \sum_{i=0}^{n} N_{i,p}(u) P_i \qquad (1)$$

where P_i denotes the control points. $n + 1$ is the number of control points and $N_{i,p}(u)$ are B-spline basis functions of degree .
B-spline basis functions, $N_{i,p}$(u), are defined recursively as:

$$N_{i,0}(\mathrm{u}) = \begin{cases} 1 & if\ u_i \leq u \leq u_{i+1} \\ 0 & otherwise \end{cases}$$

$$N_{i,p}(\mathrm{u}) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u) \qquad (2)$$

The basis function, $N_{i,p}$(u), depend only on the value of p and the values in the knot vector.

$$\mathrm{U} = \{u_0, u_1, \dots, u_m\}$$

,where m+1 is the number of knots.
The forth degree function is used for uniform cubic B-spline.

$$N_{i,0}(\mathrm{u}) = \begin{cases} 1 & if\ u_i \leq u \leq u_{i+1} \\ 0 & otherwise \end{cases}$$

$$N_{i,4}(\mathrm{u}) = \frac{u - u_i}{u_{i+4} - u_i} N_{i,3}(u) + \frac{u_{i+5} - u}{u_{i+5} - u_{i+1}} N_{i+1,3}(u)$$

$C(u) = \sum_{i=0}^{3} N_{i,4}(u) P_i \quad 0 \leq u \leq 1$

With Cox-de Boor recursion formula, the basis functions can be calculated and the k-th segment can be written as:

$$\mathrm{P(t)} = [1 \quad t \quad t^2 \quad t^3\ ] M \begin{bmatrix} P_k \\ P_{k+1} \\ P_{k+2} \\ P_{k+3} \end{bmatrix} \qquad (3)$$

Where k = 0, 1, …, n-3 and 0 ≤ t ≤ 1, and where

$$M = \frac{1}{6} \begin{bmatrix} 1 & 4 & 1 & 0 \\ -3 & 0 & 3 & 0 \\ 3 & -6 & 3 & 0 \\ -1 & 3 & -3 & 1 \end{bmatrix}$$

Catmull-Rom spline was presented by Catmull and Rom [5] and can be drawn using the following linear equation:

$$P(t) = [1 \quad t \quad t^2 \quad t^3] M \begin{bmatrix} P_k \\ P_{k+1} \\ P_{i+2} \\ P_{i+3} \end{bmatrix} \qquad (4)$$

where

$$M = \frac{1}{2} \begin{bmatrix} 0 & 2 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 2 & -5 & 4 & -1 \\ -1 & 3 & -3 & 1 \end{bmatrix}$$

The catheter tip has its particular shape so that it can be easily engaged into coronary ostium. Judkins catheter is the most popular catheter. The shapes of Judkins catheter for right coronary arteries and left coronary arteries are different. Each requires different manipulation. Unlike guidewire, catheter has its own shape at the end. Their mechanical properties are different. Consequently, the combination of the guidewire and catheter behave differently.

During the catheterization, a guide wire first is inserted and advanced into the aortic root under the X-ray guidance. After the guidewire is placed in the aortic root, the catheter is advanced over the guidewire until the tip reaches the aortic root. Then, the guidewire is withdrawn.

2. Implementation

For the implementation of the simulation, Unity was used. It is a cross-platform game engine which can be used for video games, simulations for computers, consoles and mobile devices. Scripts can be written in C# and JS for the game engine.

B-Spline has been used for tracking a guidewire in X-ray images. So, guidewire can be simulated with B-Spline. However, the combination of guidewire and catheter moves differently than guidewire itself moves in aorta. Catmull-Rom spline may work better to simulate the combination of guidewire and catheter when a catheter advances over a guidewire.

Figure 1 shows the combination of a catheter and a guidewire which is simulated through Catmull-Rom spline. The white spheres are control points. The white line is Catmull-Rom spline with the control points. The blue line is B-Spline with the same control points. As a catheter advances into the aortic arch along with a guidewire, the combination of the catheter and the guidewire changes its shape of curve. To simulate the catheter bends at 45 degree, two control points are used, P_3 and P_4. In Figure 1, there are two gray spheres, S_0 and S_1, that represents locations that the catheter touches the surface of the aorta. As the catheter touches the aorta surface, it bends at an angle. As the catheter advances to the aortic root, the control points move closer to those two spheres, S_0 and S_1.

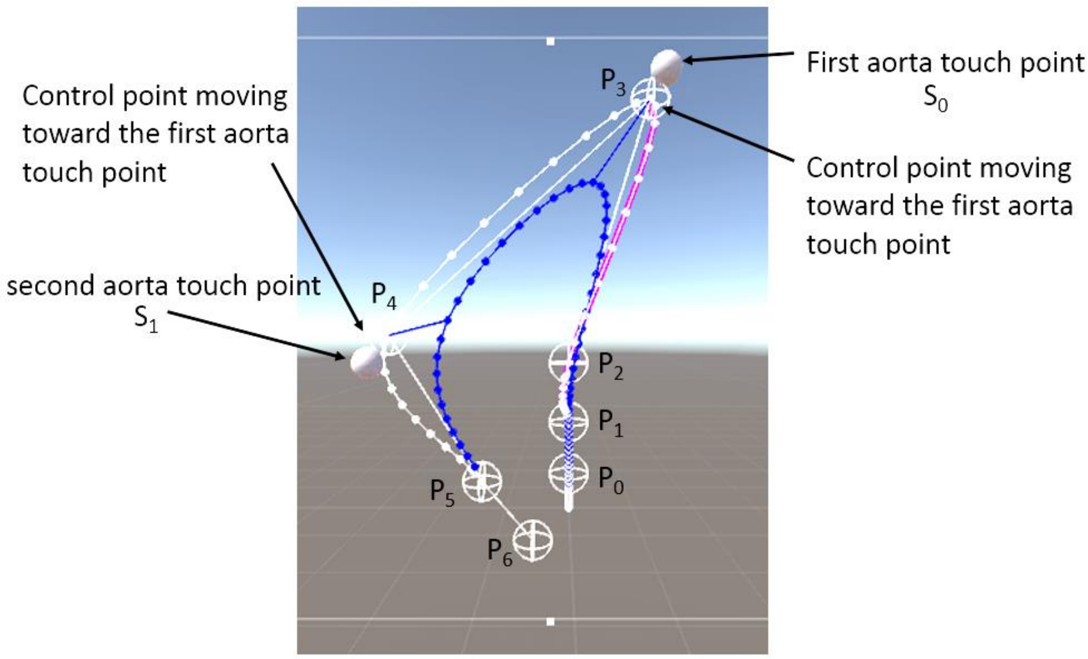

Fig.1. Splines for guidewire in the aortic arch

Figure 2 shows how the catheter is simulated with control points for Catmull-Rom spline. It shows how the shape of spline can be modified by moving the control points.

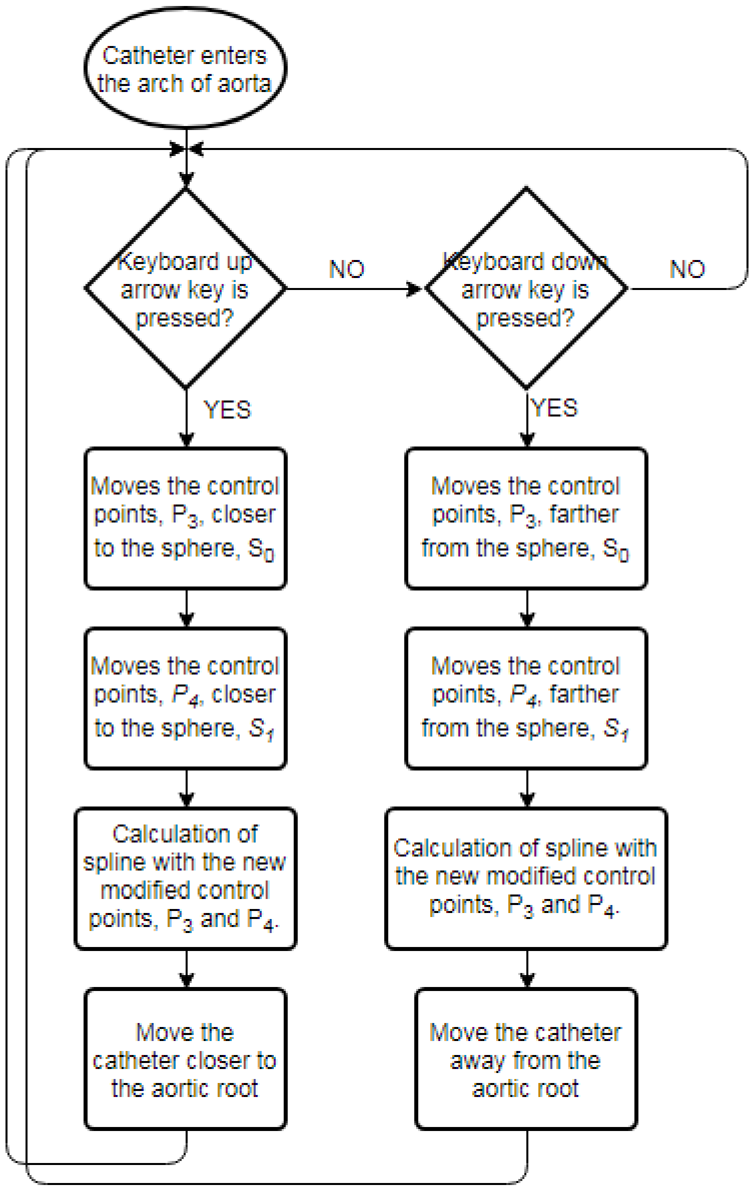

Fig.2. Flow Diagram for algorithms of spline for catheter movements in the aortic arch

In Figure 3, the catheter, which is a pink line, advances to the aortic root from the descending aorta (a), through the aortic arch (b) reaching to the aortic root (c). As the catheter moves closer to the aortic root, the control points, P_3 and P_4, moves closer to the spheres, S_0 and S_1. The movement of the catheter is controlled with inputs from a keyboard. An up arrow key initiates the catheter movement toward the aortic root. It simulates pushing the catheter into the aorta. A down arrow key initiates the catheter movement away from the aortic root. It simulates pulling the catheter away from the aortic root.

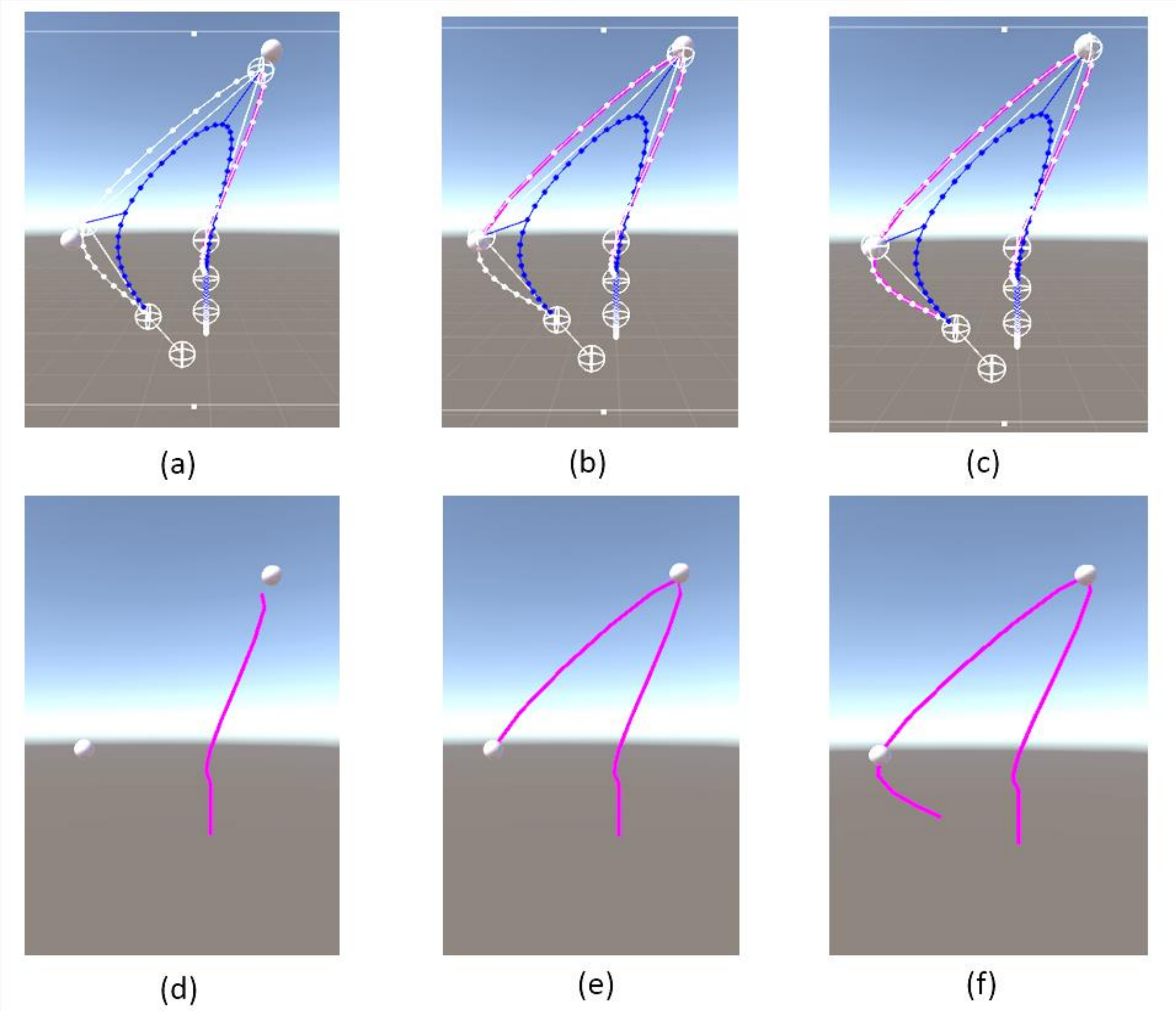

Fig.3. Simulated catheter in the aortic arch. (a), (b), (c) are shown with control points. (d), (e), (f) are simulations of the catheter

3. Conclusion

In this paper, a catheter and a guidewire in an aorta were simulated with splines. The simulation of a guidewire was simulated with B-Splines. The simulation of the combination of the catheter and the guidewire used Catmull-Rom spline. This algorithm of the combination of B-Spline and Catmull-Rom spline may be integrated in the simulation program for training of coronary angiography, specifically for the manipulation skills of the catheter and the guidewire.

ლიტერატურა-References-Литература:

1. Wang P., Chen T., Zhu Y., Zhang W., Zhou S.K., Comaniciu D. (2009). Robust guidewire tracking in fluoroscopy. In: 2009 IEEE Conf. on Computer Vision and Pattern Recognition. 691-698.

2. Baert S.A.M., Viergever M.A., Niessen W.J. (2003). Guide-wire tracking during endovascular interventions. IEEE Transactions on Medical Imaging. 22, 965-972.

3. Chang P.-L., Rolls A., De Praetere H., Vander Poorten E., Riga C.V., Bicknell C.D., Stoyanov D. (2016). Robust Catheter and Guidewire Tracking Using B-Spline Tube Model and Pixel-Wise Posteriors..

4. Lenoir J., Cotin S., Duriez C., Neumann P. (2006). Interactive physically-based simulation of catheter and guidewire. Computers & Graphics. 30. 416-422.

5. Catmull E., Rom R.. (1974). A Class of local interpolating splines A2 - Barnhill, Robert E. In: R.F. Riesenfeld (Ed.). Computer Aided Geometric Design, Academic Press. 317-326.

მიმმართველი ძაფისა და კათეტერის სიმულაცია ვირტუალური კორონარული ანგიოგრაფიისათვის

დონგჰაკ კიმი, ირინე გოცირიძე, ზვიად ღურწკაია
საქართველოს ტექნიკური უნივერსიტეტი

რეზიუმე

კორონარული ანგიოგრაფია არის საერთო სამედიცინო პროცედურა გულის პრობლემების დიაგნოსტირებისათვის. კათეტერიზაციის შემთხვევაში, საღებავი შეყავთ გვირგვინოვან არტერიებში. რენტგენის გამოსახულების საშუალებით, ექიმებმა შეიძლება იპოვნონ კორონარული არტერიების ნებისმიერი დაზიანება. პროცედურისას გამოიყენება სპეციალური კათეტერები და მიმმართველი ძაფები. მოცემულ სიმულატორში აორტაში კატეტერისა და მიმმართველი ძაფის გადაადგილებისათვის გამოყენებულია წირის ფუნქცია. აღნიშნული სიმულატორი შეიძლება გამოყენებული იქნას ექიმების მიერ კორონარული ანგიოგრაფიის შესასწავლად საჭირო უნარ ჩვევების გამოსამუშავებლად.

СИМУЛЯЦИЯ НАПРАВЛЯЮЩЕЙ НИТКИ И КАТЕТЕРА ДЛЯ ВИРТУАЛЬНОЙ КОРОНАРНОЙ АНГИОГРАФИИ

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Резюме

Коронарная ангиография - общая медицинская процедура для диагностики сердечных проблем. В случае катетеризации краска окрашивает коронарную артерию. С помощью рентгеновского изображения врачи могут найти любое повреждение коронарной артерии. В процедуре используются специальные катетеры и направляющие нитки. В этом симмуляторе функция кривой используется для перемещения катетера и направляющей нити в аорте. Этот тренажер можно использовать для развития навыков, необходимых для изучения коронарной ангиографии врачами.