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Coronary Angiography Learning System

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Summary

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The thesis is available at the GTU library,

the abstract - on the Faculty webpage.

The Secretary of the Dissertation Council: Professor, Tinatin Kaishauri

General Description of the Work

Topics. In order to reach the competent level of the coronary angiography, one must perform the procedures by himself. The training is mostly done in a catherization laboratory. It takes certain amount of time to achieve the competency to perform a coronary angiography. To someone who has less experience of the procedure and less time of the training, it could be daunting task, which may cause medical errors. Therefore, the training outside a catherization laboratory got attention in the medical training and its advantages have been recognized. The advancements of computer technology brought the applications of the technology to the medical field. One of the applications is simulation training.

Simulation training prepares medical students or professionals with skills for coronary angiography outside of a catheterization laboratory. Simulators were developed and used for the training of coronary angiography. With the advancements of computer technology, the simulators provide virtual coronary angiography experience to students or professionals, which is close to real coronary angiography with visual and tactile feedbacks.

However, the costs of the commercial coronary angiography simulators are too high for an individual to have. Even they are not affordable to medical schools and institutes. Also, the size of the simulators is big. In order to build virtual environment for simulation, the commercial simulators are equipped with high end computer.

Simulation training has many advantages that cannot be ignored, but simulators are not readily available for its costs and size. As I developed the coronary angiography learning system, I considered these factors. It should be readily available and affordable to students and healthcare professionals who need training for coronary angiography without compromising the quality of simulation.

This coronary angiography learning system is based on simulation-based training that provides virtual experience of the coronary angiography. It facilitates the learning and acquiring skills for the procedure outside of a catheterization laboratory. Consequently, it will reduce training time to reach a certain competent level.

Objective. The objective of the work is to develop a coronary angiography learning system to train students or professionals through the simulation of coronary angiography.

Methodology. The methods of simulation for guidewire and catheter were explored. There are many studies for simulation of guidewire. The simulation methods are mass-spring model, finite element method, position-based dynamics, and spline model. In this study, two methods, mass-spring model and spline model were experimented. For the learning system, the mass-spring model was chosen for its simple algorithms and the model requires less computation. For the tools for the development of the learning system, Blender and Unity were employed. Blender is a free and open-source 3D computer graphics software. It can be used for 3D modeling, animations, visual effects, interactive 3D applications. Unity is a multi-platform game engine. A game engine is the software that helps game developers with many features for the game environments.

The main results of the work and scientific innovation. A coronary angiography learning system was developed with Blender and Unity. It has capability of serial communication with an external device. This learning system trains students and professionals through simulation training.

Applications. This learning system has been developed with Unity that is a multi-platform game engine. Through this game engine, this learning system can be run in different operating systems, iOS, Windows, and Android. The training can be done not just in a cath lab. It can be done in the various environments since it can be run in different operating systems. This learning system can be used in a school, a hospital or simulation center for learning, teaching and practicing coronary angiography.

Volume and Structure of the Work. Dissertation consists of introduction, literature review, results and conclusion. It is 101 pages long and has 35 references. It introduces simulation training and the methods to develop the learning system for coronary angiography. Chapter1 discusses about simulation training and commercial simulators. Chapter2 is an overview of coronary angiography. Through two chapters, chapter 3 and 4, I discussed two methods to simulate guidewire and catheter: mass-spring model and spline model. In the results section, I described how I designed the learning system and implemented it with Blender and Unity.

Synopsis of the work

Introduction. It describes coronary angiography. It shows how common the procedure is and the need for the simulation training.

Chapter 1. The history of simulation was described in this section. It tells how simulation training has been developed from the first flight simulator. These days, simulation training is adopted in other industries such as healthcare, military, law enforcement and transportation. Specifically, simulation training is getting popular in the training of medical field. And it became a part of training program. There are four popular simulators in the market were introduced: CathLabVR, Angiomentor, Simsuite and Procedicus VIST. The section 1.3 presents briefly those four simulators for coronary angiography. In the section 1.4, two major coronary angiography simulators ANGIO MENTOR™ and Mentice VIST® presented in detail. It shows how each simulator simulates coronary angiography based on their patents. For the tactile feedback, they have resisting force generator and carriage that handle guidewire and catheter. To detect the movements of guidewire and catheter, laser diode and optical sensors were used. Simulation training is discussed with research results in the section 1.5. Based on the researches, the metrics were presented for the assessment of coronary angiography simulation training. Those are total time, fluoroscopy time, catherization time and contrast dye volume. Out of these metrics, fluoroscopy is the good marker for proficiency. The trainees with simulation training showed better performance than those with conventional training.

Chapter 2. In this chapter, basics of coronary angiography were presented. The coronary arteries were described in the section 2.1. The section 2.2 describes contrast agent injection. Lastly, angiographic views are described. This chapter provides basic knowledge about coronary angiography and helps to understand the coronary angiography learning system.

Chapter 3. This chapter introduces theoretical background of mass-spring model that was used for the simulation of guidewire and catheter. In the section 3.2.1, a particle system is presented. In the section 3.2.2, the ordinary differential equation solvers are introduced: Euler's method, Mid-point method, and Runge-Kuntta method. With the ordinary differential equation solver, each particle's forces and positions. The section 3.3 shows how to calculate each particles' forces and positions with the ordinary differential equation solver. Guidewire and catheter are modelled after this particle system. Through this algorithm, the guidewire and catheter are simulated. In the section 3.4, it introduces collision detection. As guidewire and catheter moves in the aorta, they will hit the surface of the aorta and bend and rotate. This section shows how to handle the collision between guidewire and catheter and the surface of aorta. Especially, it presents in detail about collision on a plane since the collision between guidewire and aorta is collision on a plane.

Chapter 4. In this chapter, spline model is examined for the simulation of guidewire and catheter. Different types of spline are introduced and compared: natural cubic spline, Hermite cubic spline, and Catmull-Rom spline, cubic B-spline. The spline model was considered because there are researches on tracking a guidewire in fluoroscopy. B-spline was most used to track guidewire in fluoroscopy.

Results. In this section, the coronary angiography learning system was introduced and described in detail. The process of development is presented. It also discussed how Blender and Unity are used in developing the learning system.

The guidewire and catheter move according to the mass-spring model. A particle system was used to build guidewire model. Particles connected with spring present a mass-spring model. And its dynamics are governed by 1^{st}-order differential equation (ODE) with position, speed and acceleration.

And the interactions between the guidewire and catheter and aorta are controlled by collision detection and collision response. Different methods for collision detection were presented. The algorithms for the detection were studied.

The movement of guidewire and catheter was simulated using a spline model. All the theoretical backgrounds were discussed in chapter 4. Based on the spline that a guidewire makes in the aorta, the type of the spline was B-Spline. The combination of guidewire and catheter made a Catmull-Rom spline.

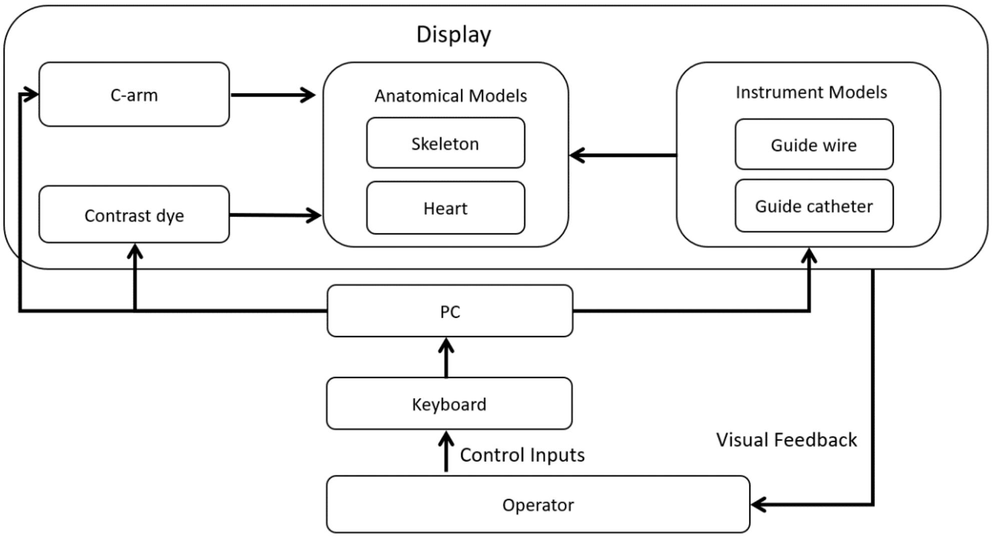

Figure 1. Schematic Diagram of Coronary Angiography Learning System

The coronary angiography learning system was developed to train students and professionals. The system consists of four modules: C-arm, Contrast dye, Anatomical Models and Instrument Models.

The C-arm module is for angiography imaging. By controlling the C-arm, the operator may have different angiographic views. As it was discussed before, depending on the coronary artery, a specific angiographic view is required. The C-arm module also simulates an activation of x-ray as the operator moves or manipulates guidewire or catheter and injects contrast dye to examine coronary arteries. During coronary angiography, the patient bed had to be moved for a better angiographic view. This bed movements were simulated by panning x-ray images.

The contrast dye module simulates the injection of contrast dye. The module visualizes coronary arteries. It also builds a coronary artery with stenosis according to input parameters of segment of coronary artery and severity of stenosis as discussed in the 2.2. As the heart beats, the coronary arteries move as the heart moves. The real-time beating heart was animated to simulate the contrast dye injection.

Anatomical model module includes models of heart and skeleton. The heart beating is animated by this module. The methods of modelling the heart and coronary arteries and skeleton are described in the section 2.2.

Figure 2. Blender and Unity logos and their initial screenshots: (a) blender (b) unity

Instrumental model module contains guidewire and catheter. It simulates guidewire and catheter in the aorta.

In order to reconstruct coronary arteries graphically, Blender(v2.79) was employed. Blender is a free and open-source 3D computer graphics software. It can be used for 3D modeling, animations, visual effects, interactive 3D applications. It is based on Python programming language. 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.

Unity is a multi-platform game engine. A game engine is the software that helps game developers with many features for the game environments. It means that game developers do not need to write programs from the scratch. And multi-platform means that games that is developed with Unity can be run in many platforms such as iPhone, Windows, iOS, Android and so on. With Unity, there are many possibilities to run the applications.

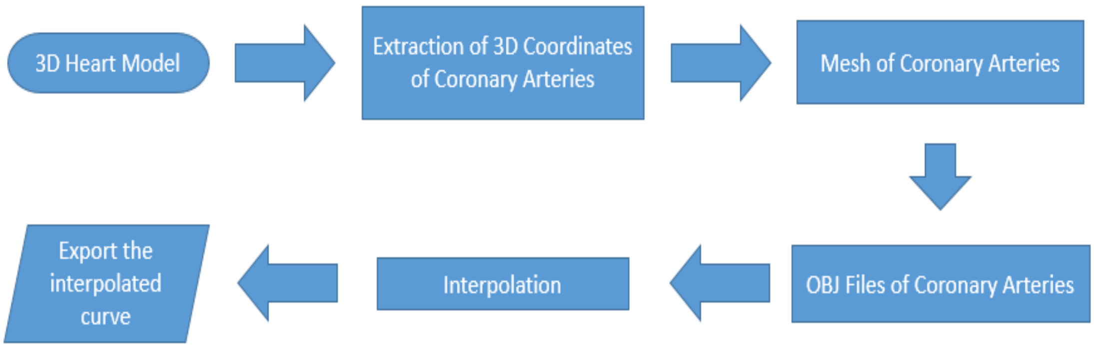

Figure 3. Flow Chart of 3D modeling

After the file was imported to Blender, each coronary artery was identified. Each artery was connected according to the coronary artery tree. The centerlines of the coronary arteries were delineated manually in the middle of the coronary arteries on the surface of the heart. For this, several scripts were written in Python programming language in order to automate the manual process such as getting 3D coordinates of each vertex, saving them as an obj file, drawing curves and converting curves into meshes.

Since the arteries have different lengths, the curves contain different number of vertices. Each curve was interpolated with MATLAB. The MATLAB code, interparc.m, was downloaded from a MathWorks forum by John D'Errico. The code interpolates the points of a curve in 3 dimensions. It produces evenly spaced points along the same curve. This code provides several options for interpolation: linear, pchip (for arc length), spline and csape (for a closed curve). The arteries were interpolated in spline to make them look smooth and it is the method that may be the most accurate according to the author. The interpolation makes easier to control the simulation and smooth curves without any sudden variation. The long coronary arteries such as LCX, LAD, and RCA have 50 points from the interpolation. Other coronary arteries have 25 points.

The beating heart is simulated through the periodic scale changes of the heart object. As the scale of the heart changes, the scales of the coronary arteries changes at the same frequency.

The number of the coronary arteries is not as big as the real image of coronary arteries. Since the purpose of the coronary angiography is to show the blood flow in the coronary arteries and to find any blockage in the coronary arteries. The coronary arteries were included only those that are parts of coronary tree in the SYNTAX score system as in the section 2.2 Contrast Dye Module.

According to the AHA classification, the coronary arteries are divided into 16 segments as seen in the section 2.2. For the assessment of coronary stenosis, there are four categories of lesion severity.

1. Minimal or mild CAD, narrowings<50%
2. Moderate, stenosis between 50% and 75%
3. Severe, stenosis between 75% and 95%
4. Total occlusion

The learning system can provide variety of coronary angiography simulations. For example, each simulation can be run with parameters for the location of stenosis and the severity of stenosis. The parameters can be a segment number and a severity. With those parameters entered by an operator, abnormal coronary arteries may be created with a narrow diameter in a specified coronary artery. In this way, abnormal coronary arteries can be created also with other pathological characteristics. The database of coronary arteries may be built easily and used for training to find the stenosis and other anomaly due to the stenosis. A training program can be developed so that trainees can pinpoint arteries to address and come up with treatments.

These days, games are not just 2D graphics with awkwardly moving objects. Thanks to the advancement of computer technology, games became more sophisticated and real in 3D graphics. Many simulation games simulate well the experiences of flying planes or the fight jets, driving cars. Unity has the physics system that makes simulations look real through the applications of physics. The movement of an object and collisions between objects can be made in realistic ways by the physics system in the Unity game engine.

This physics engine makes easy for modelling of guidewire and catheter. A software programmer may not need to write codes to simulate collision, collision response and other physics laws for rigid bodies of guidewire and catheter.

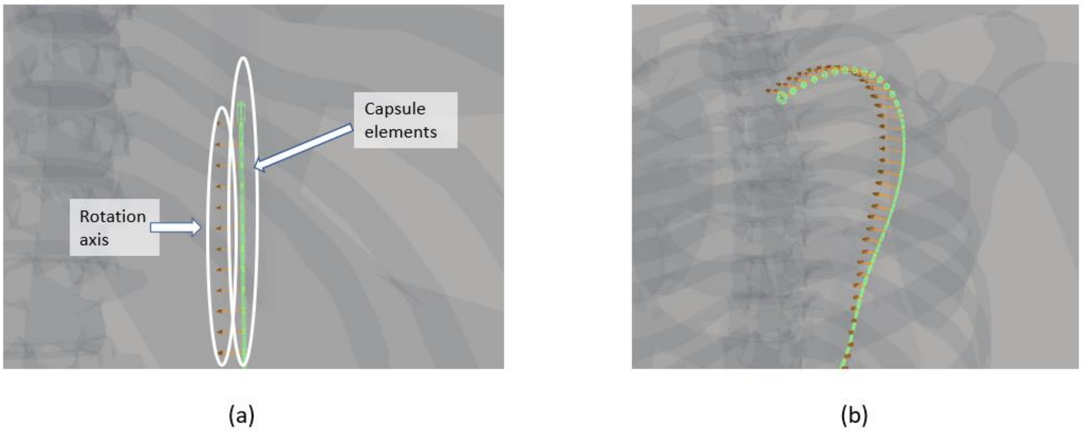

Figure 3. Guidewire in the mass-spring model

As the guidewire moves in the aorta, it does not collide with the surface as a ball hits the wall. Since the aorta is soft body, as the guidewire collides with the aorta surface, instead of bouncing off, it slides along with the surface of the aorta. It can be simulated by setting the parameter of bounciness to zero. In this way, the collision is made as the collision with a soft body which absorbs all the energy.

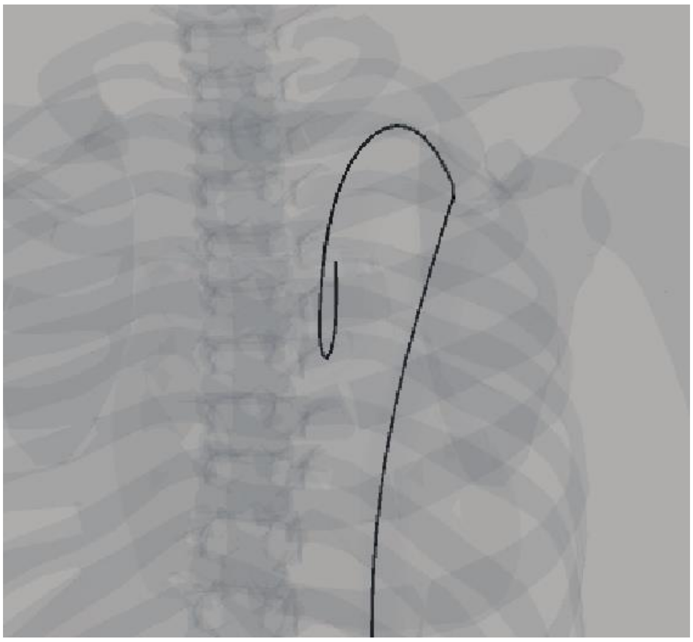

Figure 4. Simulated Guidewire in Aorta

As it was mentioned, the guidewire was represented with multiple objects connected with spring joints. Basically, the guidewire was modelled with a mass-spring system. As it is shown previously, the movement of guidewire only and the movement of guidewire and catheter together are different. The guidewire moves along with cubic spline path, whereas the combination of guidewire and catheter moves along with Hermite spline path. It can be simulated by changing the stiffness of the spring joints with high spring constant. With a low spring constant, the guidewire becomes more flexible and with high spring constant, it gets stiffer.

Inputs from Keyboard	Movements of Guidewire
W	Forward
S	Backward
A	Clockwise rotation
D	Counterclockwise rotation

Table 1. Control of guidewire movements

Inputs from Keyboard	Movements of Catheter
T	Forward
G	Backward
F	Clockwise rotation
H	Counterclockwise rotation

Table 2. Control of catheter movements

Through the manipulation of the guidewire and catheter, catheter is engaged in the left coronary ostium or the right coronary ostium. The key “Shift” simulates the contrast dye injection. Depending on where the tip of catheter is positioned, LCA or RCA will be chosen for the contrast dye injection.

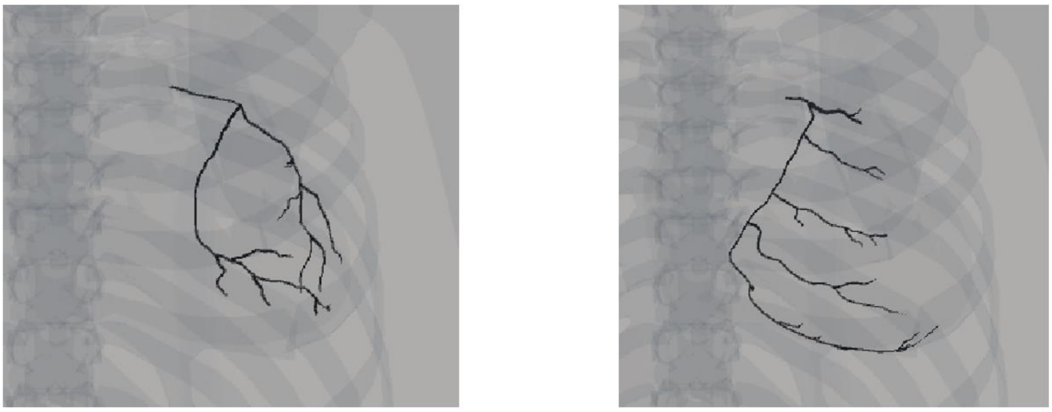

Figure 5. Simulated Dye Injection

Inputs from Keyboard	Angiographic Views
Up Arrow	Cranial
Down Arrow	Caudal
Right Arrow	Clockwise rotation
Left Arrow	Counterclockwise rotation
PageUp	Zoom in
PageDown	Zoom out

Table3. Control of C-arm

In order to connect the graphic simulation to the analog inputs, micro controller may be added as a control unit. Arduino was chosen for the control unit. Arduino is an open-source platform consisting of both a physical programmable circuit board and a piece of software for programming the physical board.

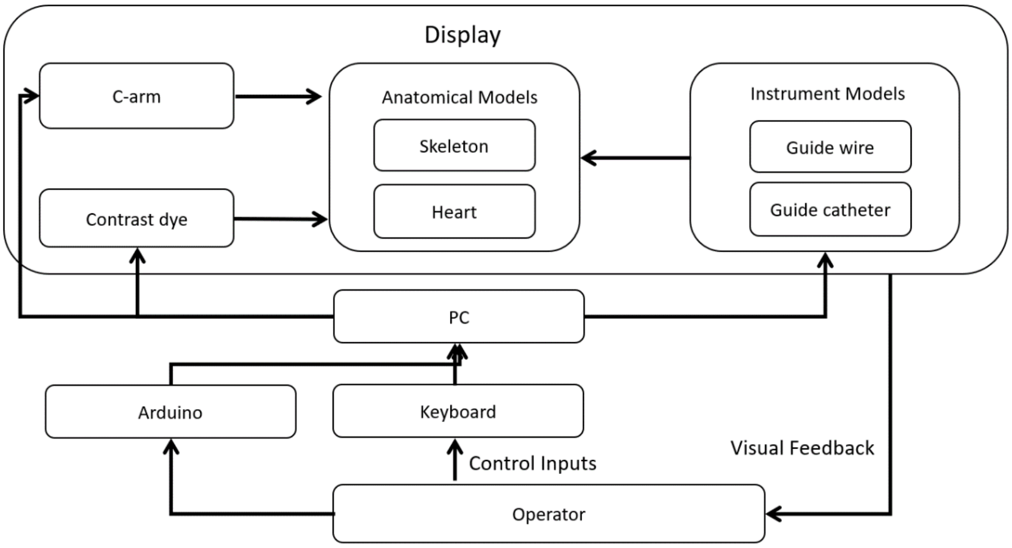

Figure 6. Schematic Diagram of Coronary Angiography Learning System with Arduino

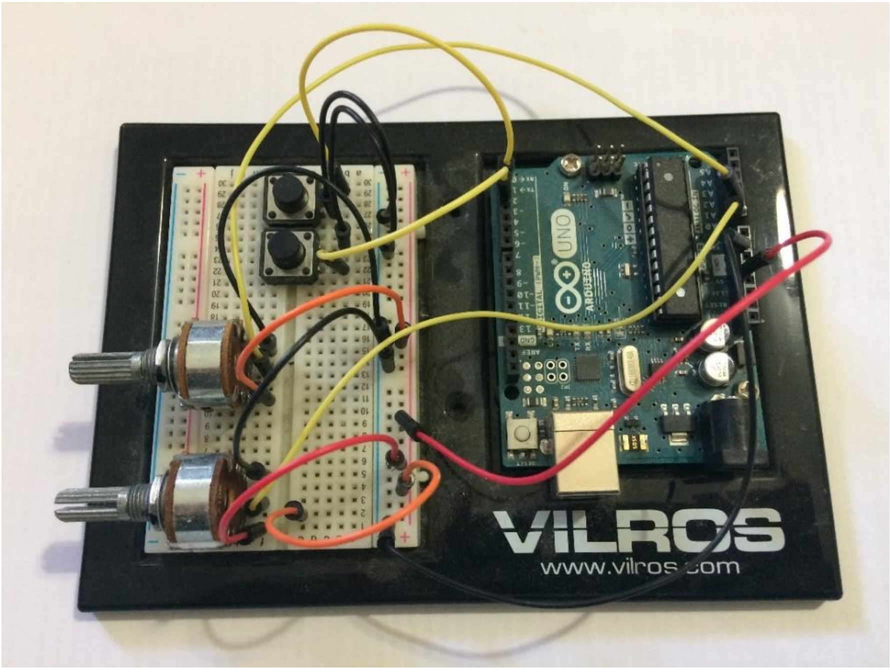

Figure 7. Arduino circuit for the control of the instrumental model module and the contrast dye module.

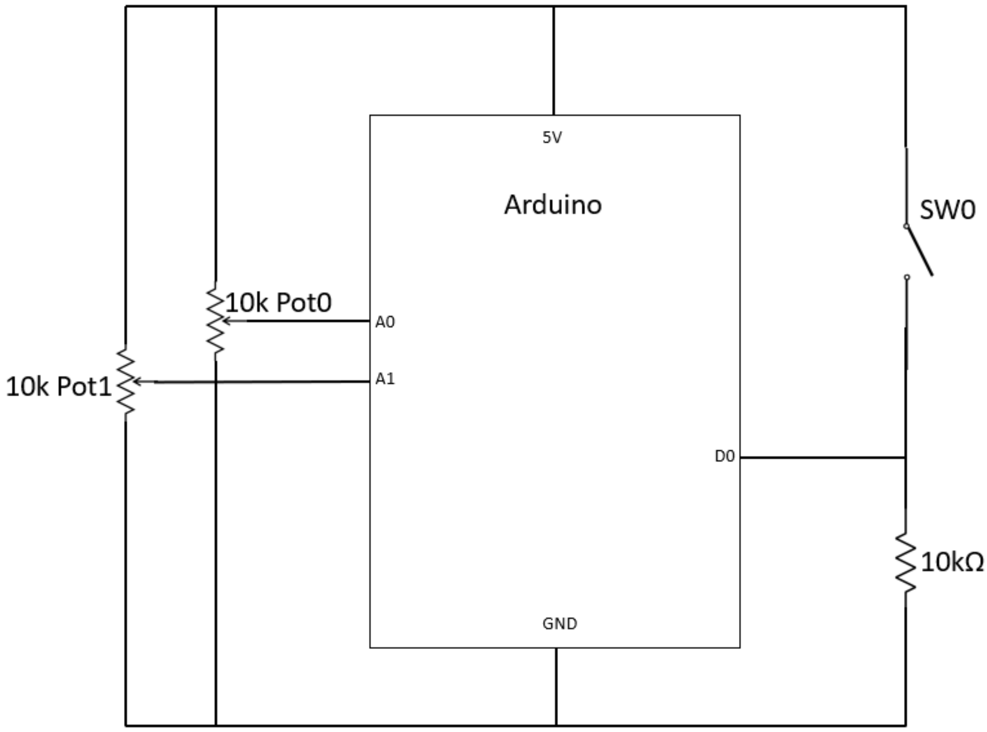

Figure 8. Arduino Circuit for Coronary Angiography Learning System

With Arduino, the learning system works just same as with a keyboard. The catheter and guidewire movements and the contrast dye injection were simulated through the Arduino. So, it proves that this system can easily be expanded to external haptic device for tactile feedback. The commercial haptic device can be added or the customized device that can detect movements of guidewire and catheter and give tactile feedback according to the movements.

Conclusion

In this paper, a coronary angiography learning system is presented. This system is designed and developed for simulation training. By the simulation of guidewire and catheter, contrast dye injection, and C-arm, the trainee can acquire skills for coronary angiography outside of a catherization laboratory.

The learning system was designed with a computer graphic software, Blender (2.79). And the simulations are implemented with a game engine, Unity3D, which also provide a physics engine for realistic movements of guidewire and catheter in aorta. Through the learning system, trainees will have more time to practice the procedure and quickly get familiar to the procedure.

The virtual experiences with the learning system will improve skills for coronary angiography and consistency of performance of coronary angiography and decrease errors. Consequently, it will decrease the time of training to reach a certain competent level in which a trainee can follow all the procedural steps unconsciously. The reduced training time will reduce the cost of training since the cost is proportional to the time.

However, the purpose of the simulation training is to transfer the effects of achieved skills through the simulation training to the real coronary angiography. The transferability from this coronary angiography learning system must be evaluated.

One way to increase the transferability of the skills is to add the capability of tactile feedback to this learning system. Currently, the learning system is capable of visual feedback only through display. For this reason, this learning system has capability of serial communication with external device. Once the control module, which can provide tactile feedback, is added to this learning system, the transferability would increase greatly.

Then, a question arises regarding the method of measuring the transferability and competent level. As it was discussed before regarding the assessment of coronary angiography simulator training, metrics have to be employed such as total procedure time, fluoroscopy time, catherization time for LCA and RCA and the volume of contrast dye. The metrics-based assessment of the skills must be combined together with the learning system.

This learning system was developed with Unity which is a multi-platform game engine. This gives enormous opportunities for expansion of this system because of the developing tool, Unity. This learning system was developed for

Windows operating system. But, Unity can easily convert it so that it can be run in iOS or in iPhone with some modifications.

Through the virtual experience of the coronary angiography, the coronary angiography learning system will provide simulation training for students, professionals and educators in various settings such as school, hospital, and simulation center.

Publications and Conference Participations

1. D. Kim, I. Gotsiridze, Z. Gurtskaia, Computer Simulation of Contrast Agent Injection in Coronary Angiography, Journal of Technical Science & Technologies, 2017, 6, 2, 11-13.
2. D. Kim, I. Gotsiridze, Z. Gurtskaia, Simulation of Contrast Agent Injection with the Control of X-Ray Fluoroscopy in Coronary Angiography, Intellectual, 2018, 35, 111-118.
3. D. Kim, I. Gotsiridze, Z. Gurtskaia, Guidewire and Catheter Simulation for Virtual Coronary Angiography, Transactions Automated Control Systems, 2018, 1, 25, 67-72
4. D. Kim, Coronary Angiography Learning System, Students 84^{th} International Scientific Conference, Georgian Technical University, Tbilisi, Georgia, 2016
5. D. Kim, Graphical Simulation of Coronary Angiography, Students 86^{th} International Scientific Conference, Georgian Technical University, Tbilisi, Georgia, 2018

Abstract

This paper presents coronary angiography learning system that is designed and built for coronary angiography training. This learning system is based on simulation training to prepare healthcare professionals for coronary angiography, providing virtual hands-on experience outside a catherization laboratory. To provide this experience to a wide range of people, it is designed to be simple and affordable.

This system has three components: display, pc, and keyboard. Display provide visual feedbacks. A keyboard is an interface between a trainee and the system. PC process the graphical calculations and execution of algorithms for the simulations according to the inputs from a trainee.

The simulation is the result of the interactions of the following components: imaging, instrument model (guidewire and catheter,) anatomy model (heart, skeleton, coronary arteries), and contrast dye. These four components are integrated in the system.

Anatomy model was built with a software, called Blender(v 2.79). It is a popular free open-source tool for computer graphic design. The software helps to modify and build a model. The model of coronary arteries was created with the imported heart model.

The simulation of the guidewire and catheter was implemented with a software, UNITY, that is a multi-platform game engine. It includes physics engine that makes the simulation seem real. The guidewire and catheter were modelled after the mass-spring model.

Imaging is regarding angiographic views. As angiographic views depend on the position of C-arm, the imaging component controls the C-arm's position and provides desired images through panning and zooming.

Contrast dye makes the coronary arteries visible under X-ray. This component is related stenosis. It creates coronary arteries with stenosis based on the two parameters: number of segment and the level of severity.

The coronary angiography is a procedure to visualize coronary arteries and locate abnormalities such as stenosis. The system starts with catherization introducing a guide wire and catheter into the aortic root. The next step is cannulation. Once the catheter is positioned, it is manipulated to be engaged in an ostium. The manipulation of the catheter is done through keyboard inputs. It includes forward and backward movement, and clockwise and counterclockwise rotation.

Once the cannulation is done, contrast dye is injected. The injection is activated through the input from the keyboard. As the contrast dye is injected, the coronary arteries appear on the display. For the better view of coronary arteries, the x-ray angiographic images can be panned up, down, left or right and zoomed in and out while the contrast dye is being injected. The learning system will store the coronary angiography data for a review later.

This coronary angiography learning system can be a tool to expose the procedure of catherization and cannulation to a trainee. It also helps to locate any abnormal artery with stenosis.

This learning system provides visual feedback only. For the better experience of coronary angiography, the learning system is designed for serial communication through USB. It can be readily connected with an external module such as a haptic device for tactile feedback.

Simulation training is suitable for interventional cardiology, especially coronary angiography since certain number of procedures is required to reach a certain level of competency. Through the simulation training with this learning system, without real patients, the level of competency may increase quickly. Consequently, it will shorten the time and the cost of training.

It can be also an educational tool for medical students to study coronary arteries and learn to identify pathological condition of coronary arteries and for educators to prepare teaching materials.

ავტორეფერატი

ეს ნაშრომი წარმოგვიდგენს კორონარული ანგიოგრაფიის სასწავლო სისტემას, რომელიც შემუშავდა და შეიქმნა კორონარულ ანგიოგრაფიაში ტრენინგის მიზნებისათვის. ეს სასწავლო სისტემა ეფუძნება სიმულაციურ სწავლებას კორონარულ ანგიოგრაფიაში სამედიცინო სპეციალისტების მზადებისა და მათთვის ვირტუალურად, კათეტერიზაციის ლაბორატორიის ფარგლებს მიღმა, პრაქტიკული გამოცდილების მიცემას. ამ გამოცდილების ადამიანთა ფართო სპექტრისათვის მიცემას უზრუნველყოფს სისტემის მარტივი დიზაინი და ადვილი ხელმისაწვდომობა. სისტემა შედგება სამი კომპონენტისაგან, ესენია: მონიტორის ეკრანი, პერსონალური კომპიუტერი და კლავიატურა. მონიტორის ეკრანით ხდება ვიზუალური უკუკავშირის მიღება. კლავიატურით მყარდება კავშირი პრაქტიკანტსა და სისტემას შორის. პერსონალური კომპიუტერით ხდება გრაფიკული მონაცემების დამუშავება და სიმულაციის ალგორითმების შესრულება პრაქტიკანტის მიერ განსაზღვრული შესავალი მონაცემების საფუძველზე.

სიმულაცია არის შემდეგი კომპონენტების ურთიერთქმედების შედეგი: ვიზუალიზაცია, ინსტრუმენტების მოდელი (ლითონის გამტარი და კათეტერი), ანატომიური მოდელი (გული, ჩონჩხი, კორონარული არტერიები) და კონტრასტული ნივთიერება. ეს ოთხი კომპონენტი ინტეგრირებულია ერთიან სისტემაში.

ანატომიური მოდელი შექმნილია Blender (v2.79) კომპიუტერული პროგრამის გამოყენებით. იგი წარმოადგენს კომპიუტერული გრაფიკული დიზაინის პოპულარულ, ღია კოდზე დაფუძნებულ საპროგრამო გადაწყვეტას. იგი გვეხმარება მოდელის მოდიფიკაციასა და დახვეწაში. კორონარული არტერიების მოდელი შეიქმნა გულის მოდელის გამოყენებით, რომელიც საპროგრამო პაკეტში იქნა იმპორტირებული.

ლითონის გამტარისა და კათეტერის სიმულაციისთვის გამოყენებულ იქნა კომპიუტერული პროგრამა - UNITY, რომელიც მულტიპლატფორმული თამაშის ძრავის წარმოადგენს. იგი მოიცავს ფიზიკურ ძრავს, რომელიც „სიმულაციას რეალობასთან აახლოებს. ლითონის გამტარისა და კათეტერის მოდელირება სისტემის - „ზამბარა-ტვირთი“ მოდელირების ანალოგიურია.

ვიზუალიზაცია გულისხმობს ანგიოგრაფიული გამოსახულებების მიღებას. იმდენად, რამდენადაც ანგიოგრაფიული გამოსახულებები დამოკიდებულია რენტგენოლოგიური აპარატის C-რკალის მდებარეობაზე, ვიზუალიზაციის კომპონენტი აკონტროლებს C-რკალის მდებარეობას და უზრუნველყოფს სასურველი გამოსახულებების მიღებას პანორამული ან ახლო ხედის გადაღების მეშვეობით.

კონტრასტული ნივთიერება ახდენს კორონალური არტერიების რენტგენოლოგიურ ვიზუალიზაციას. ეს კომპონენტი კავშირშია სტენოზის

მოდელირებასთან. იგი ახდენს სტენოზირებული კორონარული არტერიების ფორმირებას ორი პარამეტრის - სტენოზირებული უბნების რაოდენობისა და სტენოზის ხარისხის, გათვალისწინებით.

კორონარული ანგიოგრაფია წარმოადგენს პროცედურას, რომლის დროსაც ხდება კორონარული არტერიების ვიზუალიზაცია და პათოლოგიური უბნების, მაგალითად - სტენოზის, ადგილმდებარეობის გამოვლენა. სისტემა მოქმედებაში მოდის კათეტერიზაციის ეტაპით, რომლის მსვლელობაში ხდება ლითონის გამტარისა და კათეტერის შეყვანა აორტის ფესვში. შემდეგი ეტაპია კანულაცია. კათეტერის შეყვანის შემდეგ ხდება მისით მანიპულირება ისე, რომ იგი აღმოჩნდეს კორონარული არტერიის შესართავში. მანიპულირება ხორციელდება კლავიატურის მეშვეობით. ეს მოიცავს კათეტერის მოძრაობას წინა და უკანა მიმართულებით, ასევე - მის მობრუნებას საათის ისრის მოძრაობის მიმართულებით ან მის საწინააღმდეგოდ.

კანულაციის დასრულების შემდგომ ხდება რენტგენოკონტრასტული ნივთიერების შეყვანა. ინექციის ფუნქციის აქტივაცია ხდება კლავიატურიდან მიცემული ბრძანებით. კონტრასტული ნივთიერების შეყვანის პარალელურად ხდება მონიტორის ეკრანზე კორონარული არტერიების ვიზუალიზაცია. კორონარული არტერიების უკეთ დათვალიერებისათვის შესაძლებელია რენტგენოკონტრასტული ნივთიერების შეყვანის პარალელურად რენტგენოლოგიური ანგიოგრაფიული გამოსახულებების პანორამული ხედის ზემოთ, ქვემოთ, მარცხნივ და მარჯვნივ გადაადგილება, ასევე - გამოსახულების გადიდება და დაპატარავება. სასწავლო სისტემა შეინახავს მონაცემებს კორონარული ანგიოგრაფიის შესახებ მოგვიანებით ეტაპზე განხილვისათვის.

კორონარული ანგიოგრაფიის სასწავლო სისტემა შესაძლოა იყოს ინსტრუმენტი, რომლის მეშვეობითაც პრაქტიკანტი გაეცნობა კათეტერიზაციისა და კანულაციის პროცედურას. იგი ასევე გვეხმარება, გამოვავლინოთ პათოლოგიურად შეცვლილი არტერია სტენოზის უბნებით.

ეს სასწავლო სისტემა გათვლილია მხოლოდ ვიზუალური უკუკავშირის მიღებაზე. კორონარულ ანგიოგრაფიაში გამოცდილების მიღების გაუმჯობესების მიზნით სასწავლო სისტემაში გათვალისწინებულია სერიული კომუნიკაციის ფუნქცია უნივერსალური სერიული პორტის (USB) მეშვეობით. ტაქტილური უკუკავშირის მისაღებად სისტემასთან ადვილად არის შესაძლებელი გარეგანი მოდულის, მაგალითად - ჰაპტური მოწყობილობის, მიერთება.

სიმულაციური ტრენინგი გამოსადეგია ინტერვენციული კარდიოლოგიის, განსაკუთრებით კორონარული ანგიოგრაფიის სფეროში ვინაიდან კომპეტენციის განსაზღვრული დონის მისაღწევად საჭიროა პროცედურების გარკვეული რაოდენობის ჩატარება. ამ სასწავლო სისტემით სიმულაციური ტრენინგი იძლევა საშუალებას, მოხდეს კომპეტენციის

დონის სწრაფი ამაღლება რეალურ პაციენტებთან მუშაობის გარეშე. შედეგად, მცირდება ტრენინგის ხანგრძლივობა და მისი ღირებულება.

მისი გამოყენება ასევე შეუძლიათ მედიკოს-სტუდენტებს კორონარული არტერიებისა და მათი პათოლოგიების შესახებ ცოდნის მისაღებად და პედაგოგებს სასწავლო მასალების მომზადებისათვის.