Computers in Biology and Medicine 43 (2013) 2046–2052

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Virtual reality aided visualization of fluid flow simulations with application in medical education and diagnostics

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ARTICLE INFO

Article history:
Received 3 July 2013
Accepted 3 October 2013

Keywords:
Virtual reality simulator
CT scan
3D model reconstruction
Finite element method
Shear stress computation
3D visualization
Full 3D interaction

ABSTRACT

Medical education, training and preoperative diagnostics can be drastically improved with advanced technologies, such as virtual reality. The method proposed in this paper enables medical doctors and students to visualize and manipulate three-dimensional models created from CT or MRI scans, and also to analyze the results of fluid flow simulations. Simulation of fluid flow using the finite element method is performed, in order to compute the shear stress on the artery walls. The simulation of motion through the artery is also enabled. The virtual reality system proposed here could shorten the length of training programs and make the education process more effective.

1. Introduction

Virtual reality (VR) is an emerging technology that can be applied in many different areas. It can be observed as a combination of human-computer interfaces, graphics, sensor technology, high-end computing and other modern technologies that all work together to enable a user to interact actively with an artificial computer-generated environment [1]. Today virtual reality has been successfully applied in areas like engineering, architectural design, but it is most widely used in the domain of entertainment and communication. It is possible to use the significant progress in these areas and to apply VR technology in some new domains [2]. Several studies came to a conclusion that VR technology could be very useful in education [3,4]. Virtual reality can be potentially applied in medical education, training and diagnostics. VR applications achieved a lot of success in pilot and military training and this is a good proof of the great potential of this technology. Hardware and software necessary for a VR simulation are rapidly improved and the cost of such systems is not as high as it used to be. These are only some of the signs that show that VR may become an important tool for medical staff in the near future.

VR training and diagnostics could enable minimally invasive surgeries, thus helping to minimize the necessary hospital stay and lower the health care costs. So far, an education model created more than 100 years ago was used in education of young doctors. This approach can be drastically improved with more advanced technologies, like VR. There are many indicators that show that VR technology will be used in preoperative planning, medical education and research [5]. Today many VR simulations are developed and applied, including whole-patient anatomy models [6], interactive 3D visualization of medical images [7], skills simulators [8,9] and simulations of several simple surgical procedures, like leg surgery [10], cataract surgery [11] or laparoscopic surgery [12].

The traditional training and learning methods in medicine are based on the available cases and patients that come with certain anomalies. However this limits the possibilities of studying new cases and results in variable expertise and knowledge that medical students and trainees receive during their practice. With VR systems, this is not a problem, since computer-generated virtual patients and organs can be reviewed many times, which makes the education process more effective. VR provides a training environment where possible errors do not have consequences to the patients or the staff and equipment. Also, this type of training and education simulators could shorten the length of training programs and thus lower educational expenses.

On the other hand, there is another important part of medicine where VR can be very useful – the preoperative diagnostics. There are several proposed solutions in the area of gastroscopy,

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http://dx.doi.org/10.1016/j.compbiomed.2013.10.004

colonoscopy and bronchoscopy [13–15]. This paper introduces a method for visualization of pathological findings, which can be used for both education of medical students and analysis by surgeons and experts.

New non-invasive imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) have evolved over the years and have become important tools in medical diagnostics. Both mentioned scanners generate a certain number of 2D cross-sections (slices) of tissues. Medical doctors have learnt how to examine these 2D images by performing a mental reconstruction of anatomical structures in order to notice possible anomalies. This process is usually noted as abstract 2D thinking [16]. Of course, there were several proposed techniques to reconstruct 3D objects from 2D sliced images. But, most radiologists and experts preferred the 2D approach. One of the main reasons for this was the fact that 3D interaction was not good enough and that 3D objects were hard to be visualized on a 2D screen (monitor). The method proposed in this paper offers a complete 3D visualization, with an active 3D projector and a pair of LCD shutter glasses. Also, complete interaction with the model is enabled by using a special Data Glove and a set of electromagnetic tracking sensors.

With the method proposed in this paper, surgeons and medical experts can visualize these images in 3D and manipulate three-dimensional models created from CT or MRI scans. This can enable them to analyze the images better and to plan the operational procedure in detail, by manipulating virtual images preoperatively. This type of visualization provided by VR technologies can facilitate the work of radiologists, improve their perception of the shape and position of the anomalies and thus upgrade the diagnostics process.

Another feature of the method proposed here is the possibility to visualize the results of fluid flow simulations, for example the shear stresses on the artery walls. The artery geometry is again obtained using CT scan images. The simulation of fluid flow using the finite element method [17,18] is performed afterwards, in order to compute the shear stress on the artery walls. Finally, the model is exported in the necessary format and the artery model is visualized in 3D with the same system already mentioned above. The simulation of motion through the artery is also performed, so that the experts can have a better perception of the state of the artery. This way they can observe any probable anomalies and address the problem properly.

The paper is organized as follows: Section 2 gives a short description of the 3D model reconstruction procedure. Section 3 describes the basic equations used for the simulation of fluid flow and computation of shear stress. The basic idea of VR simulation and used equipment are presented in Section 4. The description of the VR application itself is given in Section 5. Section 6 concludes the paper.

2. 3D model reconstruction

A complex 3D geometry model of the left coronary artery (LCA) for specific patient is developed. Blood flow in the LCA is a complex time-dependent, three-dimensional flow. Therefore, the time-dependent and full three-dimensional Navier-Stokes equations have to be solved. One of the central difficulties in performing the numerical simulation of blood flow in the coronary system is to generate a finite element mesh due to the complexity of the geometry which includes all essential DICOM slices obtained from dual 64 multislice CT (MSCT) device. The 3D reconstruction of artery geometry is performed using an in-house developed software for automatic segmentation (as shown in Fig. 1) [19]. Edge detection techniques are used in combination with active contour algorithms [20–22] to segment the cross sectional areas of DICOM slices and thus to reconstruct the 3D arterial model. Graphic APIs are used in order to produce a smooth artery model. Using this approach it is possible to obtain a patient-specific arterial tree. In regions of reduced arterial opacification segmentation is manually complemented, i.e. independent external objects are removed. The in-house software developed in programming language C++ was used for this purpose together with the method proposed by Geuzaine et al. [23]. In this software the center of gravity (COG) algorithm was also used [24] and the Laplace technique [25] was employed to obtain a smooth surface of the artery.

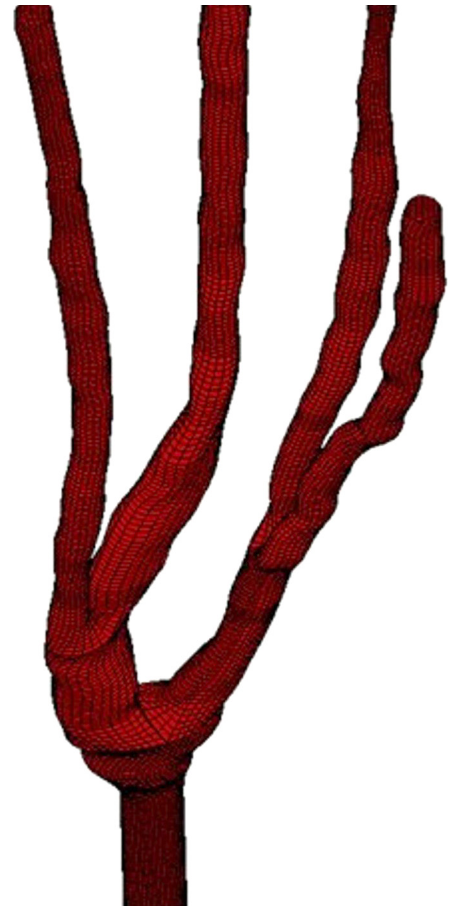

Fig. 1. Finite element mesh for the coronary artery.

After image segmentation, the finite element mesh was created. This was performed in two steps. First the Tetgen software (Hang Si, Research Group: Numerical Mathematics and Scientific Computing, Weierstrass Institute for Applied Analysis and Stochastics (WIAS), Berlin, Germany) was used in combination with the software tool developed by Hang [26] to create tetrahedrons from the surface triangles. Then the in-house developed software was used for the remeshing procedure, to create structured 3D 8-node "brick" finite elements for CFD analysis. In this remeshing procedure we also used the mentioned COG algorithm, where each tetrahedron was split into four as explained in [24], in order to obtain a pure hexahedral volume mesh. A finite element model of LCA including the part of the root aorta is shown in Fig. 2. Note that for the virtual reality simulation described in the sequel, only the left branch of the model is used.

A finite element mesh with 150,000 3D 8 node finite elements is generated using the described approach. In order to create a mesh that can give accurate results and to ensure that the solution is independent of the mesh resolution, it was necessary to carry out a mesh independence study. We first performed a simulation with a certain initial mesh resolution and obtained the simulation results. Then we refined the mesh to obtain new results and we

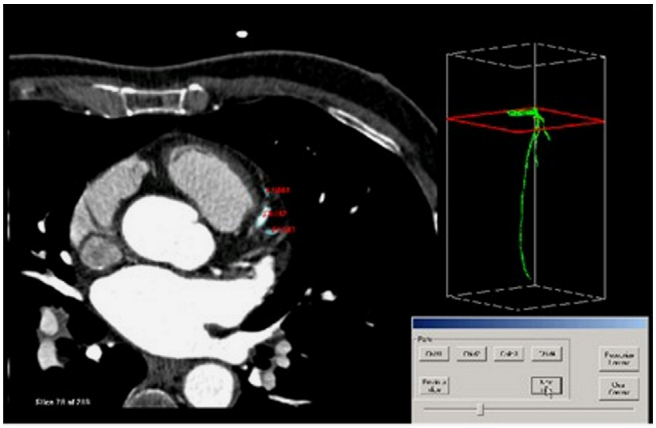

Fig. 2. 3D reconstruction from DICOM slices.

repeated this procedure until we reached a "plato", i.e. until the solutions were no longer changing more than the predefined tolerance, with the increase in the number of nodes in the mesh. When this condition was met, the mesh independence is reached. In this particular case, results using four different mesh resolutions were calculated and the mesh independence was reached at 150,000 to 200,000 finite elements, with an error less than 2%. The average shear stress at the arterial wall with different mesh resolution on the same surface parts was compared.

3. Fluid flow simulation

The three-dimensional flow of a viscous incompressible fluid considered here, is governed by the Navier-Stokes equations and continuity equation that can be written as

$$\rho\left(\frac{\partial v_i}{\partial t}+v_j\frac{\partial v_i}{\partial x_j}\right)=-\frac{\partial p}{\partial x_i}+\mu\left(\frac{\partial^2 v_i}{\partial x_j \partial x_j}+\frac{\partial^2 v_j}{\partial x_j \partial x_i}\right) \tag{1}$$

$$\frac{\partial v_i}{\partial x_i}=0 \tag{2}$$

where v_i is the blood velocity in direction x_i, ρ is the fluid density, p is pressure, μ is the dynamic viscosity; and summation is assumed on the repeated (dummy) indices, $i,j=1,2,3$. The first equation represents balance of linear momentum, while Eq. (2) expresses the continuity equation.

The boundary condition is defined such that all nodes on the wall of the artery are constrained, i.e. zero velocity is prescribed. At the inlet of the artery the initial velocity profile is prescribed, according to the values measured for the specific patient. The change of velocity through time is calculated using the measured flow rate that is shown in Fig. 3. The waveform is discretized into 400 uniformly spaced time steps. At the outlet of the artery the outflow zero pressure boundary condition is applied. For unsteady pulsatile conditions, the outlet pressure wave is prescribed. We determined pressure wave at the outlet with miniaturized tip-transducers for pressure measurement at the distal part of the coronary artery. In the analysis, it is considered that the convergence is reached when the maximum absolute change in the non-dimensional velocity between the respective times in two adjacent cycles is less than 10^{-3}.

The code is validated using the analytical solution for shear stress and velocities through curve tube [17,27]. A penalty formulation is used in our solver [28,29]. This software is intended primarily for simulations of three-dimensional fluid flow in the arteries and is capable to numerically simulate plaque formation and progression [30–32]. It was developed as a part of ARTreat FP7 project (www.artreat.kg.ac.rs) which involved participants from several organizations which are among the European leading companies for products and services in the areas of medical IT and cardiovascular and arterial surgery.

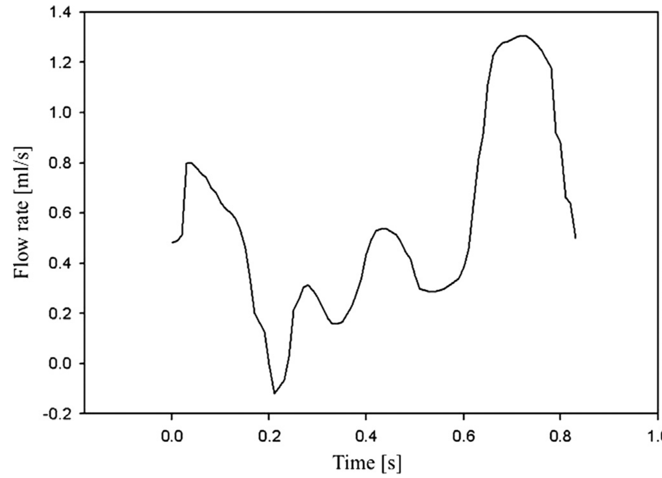

Fig. 3. Time dependence of the flow rate that is used to prescribe the velocity profile as initial condition at the inlet.

The incremental-iterative form of the equations for a time step and equilibrium iteration "i" are

$$\begin{bmatrix} \frac{1}{\Delta t}\mathbf{M_v}+{}^{t+\Delta t}\mathbf{K}_{\mathbf{vv}}^{(i-1)}+{}^{t+\Delta t}\mathbf{K}_{\mu\mathbf{v}}^{(i-1)}+{}^{t+\Delta t}\mathbf{J}_{\mathbf{vv}}^{(i-1)} & \mathbf{K_{vp}} \\ \mathbf{K}_{\mathbf{vp}}^{T} & \mathbf{0} \end{bmatrix}\begin{Bmatrix} \Delta\mathbf{v}^{(i)} \\ \Delta\mathbf{p}^{(i)} \end{Bmatrix}=\begin{Bmatrix} {}^{t+\Delta t}\mathbf{F}_{\mathbf{v}}^{(i-1)} \\ {}^{t+\Delta t}\mathbf{F}_{\mathbf{p}}^{(i-1)} \end{Bmatrix} \tag{3}$$

The left upper index "$t+\Delta t$" denotes that the quantities are evaluated at the end of time step. The matrix $\mathbf{M_v}$ is mass matrix, $\mathbf{K_{vv}}$ and $\mathbf{J_{vv}}$ are convective matrices, $\mathbf{K}_{\mu\mathbf{v}}$ is the viscous matrix, $\mathbf{K_{vp}}$ is the pressure matrix, and $\mathbf{F_v}$ and $\mathbf{F_p}$ are forcing vectors. The pressure is eliminated at the element level through the static condensation. For the penalty formulation, we define the incompressibility constraint in the following manner:

$$\mathrm{div}\,\mathbf{v}+\frac{p}{\lambda}=0 \tag{4}$$

where λ is a relatively large positive scalar so that p/λ is a small number (practically zero).

The incremental-iterative form of the equilibrium equation is

$$\left(\frac{1}{\Delta t}\mathbf{M_v}+{}^{t+\Delta t}\mathbf{K}_{\mathbf{vv}}^{(i-1)}+{}^{t+\Delta t}\mathbf{K}_{\mu\mathbf{v}}^{(i-1)}+{}^{t+\Delta t}\hat{\mathbf{K}}_{\mu\mathbf{v}}^{(i-1)}+{}^{t+\Delta t}\mathbf{J}_{\mathbf{vv}}^{(i-1)}+\mathbf{K}_{\lambda\mathbf{v}}\right)\Delta\mathbf{v}^{(i)}={}^{t+\Delta t}\hat{\mathbf{F}}_{\mathbf{v}}^{i-1} \tag{5}$$

where the matrices and vectors are

$${}^{t+\Delta t}\hat{\mathbf{K}}_{\mu\mathbf{v}}^{(i-1)}=\int_V \mu\mathbf{H}^T\mathbf{H}\,dV$$

$$\mathbf{K}_{\lambda\mathbf{v}}=\lambda\int_V \mathbf{H}^T\mathbf{H}\,dV$$

$$\begin{aligned}{}^{t+\Delta t}\hat{\mathbf{F}}_{\mathbf{v}}^{(i-1)}={}&{}^{t+\Delta t}\mathbf{R_B}+{}^{t+\Delta t}\hat{\mathbf{R}}_{\mathbf{S}}^{(i-1)}-({}^{t+\Delta t}\mathbf{K}_{\mathbf{vv}}^{(i-1)}+{}^{t+\Delta t}\mathbf{K}_{\mu\mathbf{v}}^{(i-1)}\\ &+{}^{t+\Delta t}\hat{\mathbf{K}}_{\mu\mathbf{v}}^{(i-1)}+\mathbf{K}_{\lambda\mathbf{v}})\,{}^{t+\Delta t}\mathbf{v}_{(i-1)}\end{aligned}$$

$${}^{t+\Delta t}(\hat{\mathbf{R}}_{\mathbf{S}})_{i\alpha}^{(i-1)}=\int_S \mathbf{H}^T[\lambda^{t+\Delta t}\nabla\mathbf{v}^{(i-1)}\mathbf{n}+({}^{t+\Delta t}\nabla\mathbf{v}^{(i-1)}+{}^{t+\Delta t}\nabla^T\mathbf{v}^{(i-1)})\mathbf{n}]dS$$

$$\mathbf{M_v}=\rho\int_V \mathbf{H}^T\mathbf{H}\,dV$$

$${}^{t+\Delta t}\mathbf{K}_{\mathbf{vv}}^{(i-1)}=\rho\int_V \mathbf{H}^T(\mathbf{H}^{t+\Delta t}\mathbf{v}_{(i-1)})\nabla^T\mathbf{H}\,dV$$

$${}^{t+\Delta t}\mathbf{K}_{\mu\mathbf{v}}^{(i-1)}=\int_V \mu\nabla\mathbf{H}^T\nabla^T\mathbf{H}\,dV$$

$$
\begin{aligned}
{}^{t+\Delta t}\mathbf{J}_{\mathbf{vv}}^{(i-1)} &= \rho \int_V \mathbf{H}^{\mathbf{T}}(\nabla \mathbf{H}^{t+\Delta t}\mathbf{v}^{(i-1)})\mathbf{H}\, dV \\
{}^{t+\Delta t}\mathbf{R}_{\mathbf{B}} &= \int_V \mathbf{H}^{T\,t+\Delta t}\mathbf{f}_{\mathbf{B}}\, dV \\
{}^{t+\Delta t}\mathbf{R}_{\mathbf{S}}^{(i-1)} &= \int_S \mathbf{H}^T(-{}^{t+\Delta t}p^{(i-1)}\mathbf{n} + \nabla^{t+\Delta t}\mathbf{v}^{(i-1)}\mathbf{n})dS
\end{aligned} \tag{6}
$$

A standard Petrov–Galerkin upwind stabilization technique is used for higher Reynolds (Re) number (with value of several hundreds, thousand or even greater) [28,29].

4. Virtual reality simulation

The VR simulation is developed such that it is possible to run this simulation on all standard personal computers available today. For example, on Intel Quad Core 2.4 GHz this VR simulation can be run in real-time. The time necessary for the fluid flow computation varies depending on the size of the finite element mesh, but the goal of the VR simulation is to visualize data obtained from the fluid flow computation. The used VR equipment is also commercially available. While the whole system cost may be high for some standards, virtual reality technology is becoming more affordable lately. And due to its qualities and all the improvements that it offers, it is definitely a promising tool that should be popularized and used to complement conventional diagnostics and education. The core of this VR system is the simulation engine, i.e. the PC computer that acts as an intermediator between the user and the VR input and output devices.

The schematic overview of the proposed VR system is shown in Fig. 4. This simulation is performed on a personal computer with an Intel Core 2 Duo processor and a NVIDIA Quadro graphics card. The objects that are visualized are created from CT scan images according to the procedure described in Section 2.

During the diagnostics, medical students and/or doctors are supposed to inspect a single 3D object. Therefore, there is no need for a creation of a special virtual environment – a simple, one colored background is totally acceptable. Also, it is convenient to use the so-called semi-immersive environments, i.e. a projection on a screen, rather than a full-immersive environments, i.e. a head mounted display (HMD) or a CAVE environment. The later do provide a higher level of immersion in a VR simulation, but medical applications are different than commercial video games. Here it is more practical to look at a computer screen or a large screen display, because this encourages expert team analysis of patient data. This is the reason why an active 3D projector produced by DepthQ (LightspeeD Design, Bellevue, WA, USA) was used for the stereoscopic visualization of the 3D objects. Also, in order to see the stereoscopic projection in 3D, it is necessary to wear LCD shutter glasses. Nuvision 60GX (Inition, London, UK) wireless stereoscopic glasses in combination with the 3D DepthQ single lens projector are a less expensive solution. This system creates the 3D images by projecting a different perspective of the model to each eye separately. The images for the left and right eye are synchronized using infrared signals from an IR emitter, with a frequency of 120 Hz. This whole process described above is performed automatically without any specific interaction from user's (radiologist, surgeon, medical expert) behalf. All they have to do is focus on the diagnostic task.

When analyzing a medical image, surgeons should observe the anomalies in tissues or organs. They rotate, move and scale 3D models in order to gain better insight of the stadium and state of the patient's disease. The 3D interaction requirements are the manipulation of the model's position and orientation, which means the possible change of all six degrees of freedom (DOF). The proposed VR system allows the user to directly pick a part of the 3D model and to drag it around. The electromagnetic tracking device produced by VR Space (VR Space, Taiwan), called Wintracker is used to define the position and orientation of the user's hand and/or head. Two sensors are used – the first is located on the wrist of the user's hand and is used to track the movements of the user's hand and the second one can be alternatively used and placed on the user's head, in order to track these movements. The second sensor is not necessarily used and this depends on the user's requirements for the specific simulation that is being performed. The real-time position and orientation of the user's hand and head are read from the tracking sensors and sent to the simulation engine, where the model's position and orientation are continuously updated.

In order for the system to be more immersive it is not enough to have a 3D display capabilities and a tracking system. It is necessary to have an input device that could enable the user to define what action wants to perform over the 3D model – movement, rotation, scaling. For this purpose a 5DT DataGlove (Fifth Dimension Technologies, Irvine, CA, USA) was used. This is a device that has 16 predefined gestures which can be associated with different actions within the simulation engine. In the simulation presented in this paper, six of these gestures were redefined and connected with the mentioned interactions. Fig. 5 illustrates the gestures used in this VR system and the actions associated with these gestures. Note that the three gestures in the second row are dedicated to the navigation inside the artery, which will be described in detail in Section 5.

For this specific, clinical and medical use, it is important for all the input devices to be as simple as possible and to require the least amount of training time so they can be efficiently used. With the described system users can be trained quickly to use the

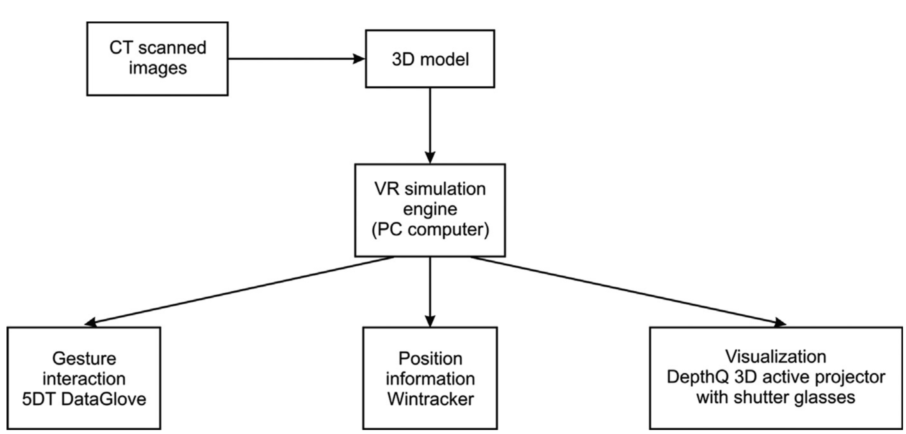

Fig. 4. Schematic overview of the VR simulator.

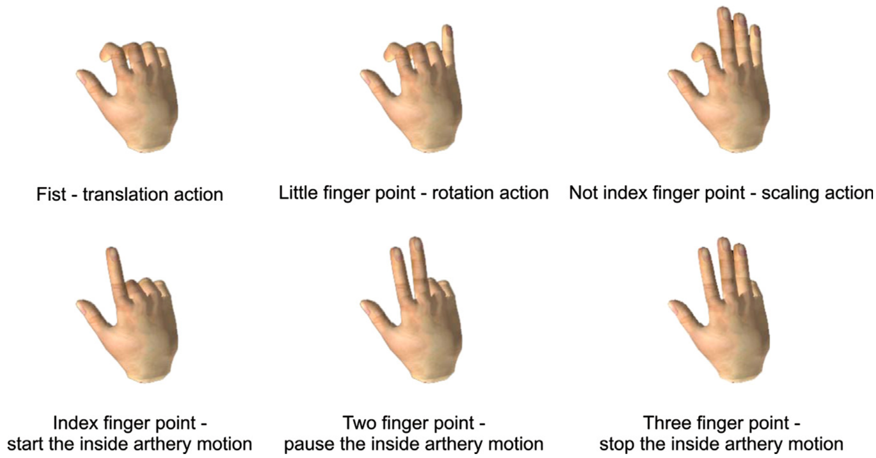

Fig. 5. DataGlove gestures and the corresponding actions.

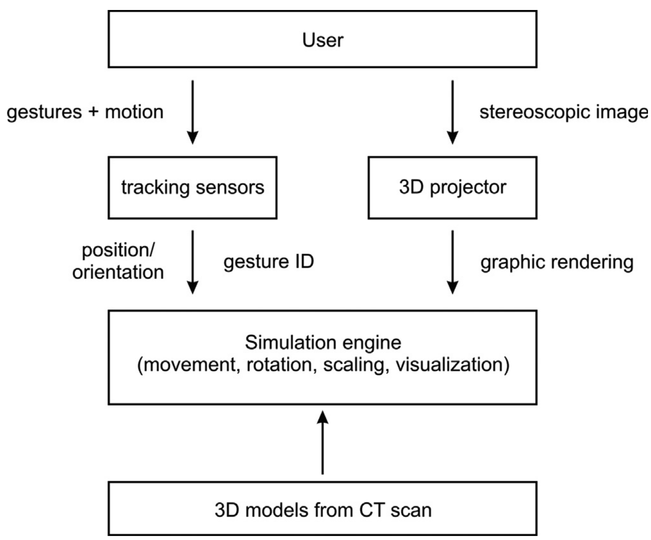

Fig. 6. Proposed VR system framework.

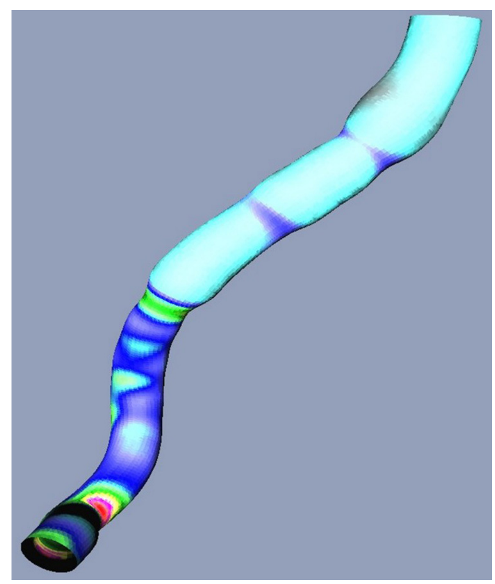

Fig. 7. Screenshot of the VR application – analyzing the artery with shear stresses obtained using finite element computation.

DataGlove, because the programmed gestures are easy to learn and to associate with the interactions they represent. Guidelines such as text instructions are provided if the user chooses this option, as an extra help during the training. Of course, this is the current state of the system and it is possible to improve it further with adding extra gesture interactions, if the need arises. But, on the other hand, it is necessary to keep in mind that the simulation and the interaction with gestures should be kept simple, because the main purpose of this type of VR simulation is not to be commercially interesting, but to be usable in clinical practice and to simplify and improve the diagnostic process.

The software that was used as a simulation engine and that has to connect all the devices together is a computer program written in Python programming language and executed using a 3D development platform Vizard VR Toolkit (WorldViz, Santa Barbara, CA, USA).

The overall framework of the proposed virtual reality medical education and diagnosis tool is shown schematically in Fig. 6.

5. Description of the developed VR application

This Section gives a short description of the developed VR application, with illustrations of the whole system. The main purpose of the application is to enable the visualization and manipulation of 3D models. In this Section several screenshots of the developed VR application are shown. The 3D model that is imported in the VR application is a carotid artery with indicated shear stress values. The procedure for obtaining this model was described in previous Sections. First, the CT scan slice images are used to define the 3D geometry, then the 3D finite element mesh is generated. Afterwards, fluid flow simulation is performed to obtain the shear stress distribution. And finally, the 3D model with shear stress distribution indicated with appropriate colors is imported into the VR application. In this environment, it is possible to move the object, zoom in and out and rotate it, in order to observe better the shear stress rates and the locations where development of plaque cells is possible, for example. Fig. 7 shows the screenshot of the artery imported in VR application.

Another function that is implemented is the motion inside arteries. During the geometry creation process, the center line of the artery is calculated. This eventually enables the VR application to simulate the motion through the artery along this predefined centerline. The motion is controlled with three gestures (the start, pause and stop gestures, shown in Fig. 5). This is an additional benefit of the proposed virtual reality application in medicine, because this way surgeons and medical students can analyze the state of the arteries, not just from the outside, but also from the inside. They have the possibility to analyze not only the state of

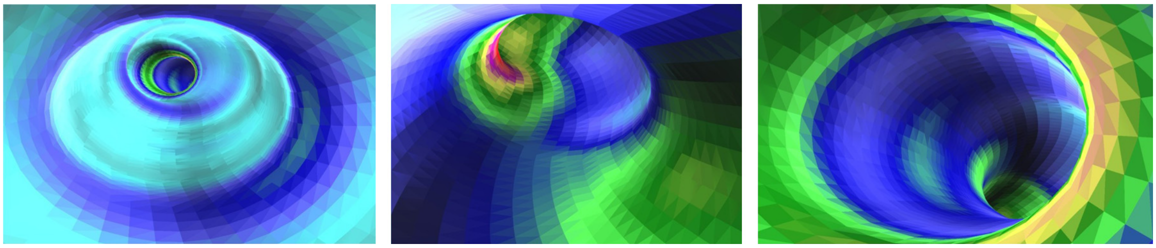

Fig. 8. Screenshots of the VR application – motion through the carotid artery.

the artery walls, but also the shear stresses that are calculated on these walls. Fig. 8 shows the screenshots of several motion phases.

In this study we decided to show how the virtual reality simulator works when it comes to visualization of arteries. Of course, the whole system can be easily adapted and successfully used for application in some other field in medicine, like visualization of tumor cells or any other. The proposed framework is very flexible and enables simple and straightforward use and further improvements. In fact, the object that is imported in the application is chosen at the start-up of the application, so it is possible to import any other organ or any geometrical object in general and visualize it in 3D and manipulate with it in real-time. The main advantage of this software in comparison with others is the fact that it enables not just to visualize the geometry of a 3D model, but also the results of a complex fluid flow simulation.

6. Conclusion

Virtual reality (VR) is a promising technology that has many potential applications, including educational purposes. It can be used in teaching young surgeons and medical students some characteristic examples of diseases. Another application of VR systems is in diagnostics – it could be used to improve the diagnostics process and to enable radiologists to obtain a better impression of the shape and size of tumor cells or infected tissue areas. VR also allows the medical staff to review the patient data several times, in order to confirm the diagnosis.

While VR has many advantages, its main drawback has always been the cost of hardware equipment. However, with the progress of technology, VR instruments are now commercially available at an acceptable and affordable price. Some of the main motivations to implement VR systems in medical education and clinical practice include the facts that these systems could reduce the educational costs, shorten the training time, lower the amount and impact of possible errors in preoperative diagnostics and operation planning among others.

The virtual reality system presented in this paper has the potential to be used as an alternative education and diagnostics tool, that could improve conventional methods mostly used nowadays. One of the goals of this system is to enhance the CT scan image analysis, by enabling medical staff to analyze these images in 3D, on a stereoscopic display, with the possibility to interact with 3D model in a way that is easy to learn and with input and output devices that are appropriate and easy to use in medical facilities.

From all the stated, it is obvious that virtual reality technologies could be implemented in daily clinical practice and although the implementation costs may be somewhat high, it is still worthwhile due to all the benefits that this system brings.

7. Summary

Virtual reality can be applied in many different areas, including engineering, architectural design, entertainment and communication. This technology could also be very useful in education. Medical education, training and preoperative diagnostics can be drastically improved with advanced technologies, like virtual reality. The method proposed in this paper enables medical doctors and students to visualize and manipulate three-dimensional models created from CT or MRI scans. They can plan the operational procedure in detail, by manipulating virtual images preoperatively with a better perception of the patient's organs. Another feature of the proposed method is that it can be used to visualize the results of fluid flow simulations, for example the shear stress distribution on the artery walls. The artery geometry is obtained using a CT scan. Then the 3D finite element mesh is generated using in-house developed software. Simulation of three-dimensional flow of a viscous incompressible fluid is performed using the finite element method, in order to compute the shear stress on the artery walls. Finally, the 3D model with shear stresses indicated with appropriate colors is imported into the VR application. The simulation of motion through the artery along the calculated centerline is another option of the proposed application. One of the goals of this system is to enhance the CT scan image analysis, by enabling medical staff to analyze these images in 3D, on a stereoscopic display, with the possibility to interact with 3D model in a way that is easy to learn. Some of the main motivations to implement a VR system like this one in medical education and clinical practice include the facts that these systems could shorten the length of training programs, make the education process more effective, lower the amount and impact of possible errors in preoperative diagnostics and operation planning among others.

In the current medical practice there is a need to address the specific issue of endovascular skills training. There are, however, several techniques to acquire new skills on patients. These include synthetic, animal based models, and more recently virtual reality trainers. Our Virtual Reality system uses a computer-generated three-dimensional model of the vascular tree, CFD calculation, allowing the user to interact with the simulation through special Data Glove interface device. Recent developments in computing power and volume rendering techniques enable a high degree of realism in simulated fluoroscopic images. Our main goal is to analyze patient specific simulations with shear stress distribution and possible plaque progression risk analysis. This system may allow rehearsal of a procedure prior to performing the real case.

Conflict of interest statement

None declared.

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