IMEDITEC 2017

ORIGINAL PAPER

Real-Time Interactive Visualization of Simulated Blood Flow Data with Physical-Based Animation

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ABSTRACT

The use of real-time visualization for visualizing simulated blood flow data in 3D game environment has great potential to enhance interactivity in visual exploration of blood flow; therefore the integration framework of chosen scientific visualization technique and physical-based animation algorithm should be developed and implemented in the game engine. This research proposed a framework on based on the idea from previous research that improves visualization of blood flow by integrates with particle based simulation method in order to allow more user interaction. Despite the variety and number of the existing method, there are still demands for new improved visualization technique with a mission to provide better information.

INTRODUCTION

One way to obtain information about blood flow in the cardiovascular system is through simulation. Although visual exploration of simulated data using flow visualization has been researched for decades, new blood flow visualization still introduced by researcher each year that covering: decisions with respect to seeding, segmentation, integral curves and the use of illustration techniques (Vilanova et. al., 2012).

Real-time interactive visualization is capability of visualization to meet real-time performance demands. As an example, the system must provide feedback to the user regarding the effect of continuous user input in less than 0.1 second, allowing fast, accurate manipulation of the environment, animation rate must at least 10 frames per second and 3D objects in virtual environment have level of fidelity (Bryson, 1996).

Recently, a physical-based animation is actively popular used in industry like computer games, movies, education and training. Increase of computing power of CPU and GPU has empowered real- time simulation to produce plausible physical effect. Many simulation method are introduced to solve many simulation issues such as fluids, rigid bodies, cloth and fracture. Every year many new algorithms are released to allow faster solution with more increased realism and also to reduce the gap with computational fluid dynamics (CFD).

Strong demand of physics-based animation in interactive application especially in medical training and education allow many computer graphics models have been designed using physics theories for surgical training use (Wang, 2009) (Kim et. al., 2013) (Etheredge et.al, 2013)(Jing et. al., 2010). Generally, in medical visualization involves standard pipeline including visualization, image processing, and graphics rendering (Wang, 2009) (Jing et. al, 2010). The latest publication in visualizing medical data in 3D is by combining MRI flow data with physics based animation (de hoon et.al, 2014).

The main propose of study is to suggest a framework for real-time interactive visualization system that integrates real-time scientific visualization and physical-based simulation technique for blood flow visualization in a small vascular tree structure from large arteries. This is important to show a complex correlation between vessel geometry and blood flow visualization technique for interactive exploration application. This paper also described the current progress of this research.

- To convert simulated data of blood flow from scientific visualization software into 3D game environment
- To introduce vector field technique in tubular structure of vascular tree to control animation of blood flow in virtual reality environment
- To integrate visualization technique and physical-based simulation technique in order to produce real-time interactive visualization system of blood

Related Works

Fundamentally, the characteristics of blood, as a fluid and vessel as surfaces to interact. Simulating fluid phenomena and deformable object are developed using numerical methods and algorithm that derived from Computational Fluid Dynamic (CFD). Navier-Stokes equations is well-known equation which is basis the most of CFD problems which formulated by Claude Navier and George Stoke (Muller et. al, 2010). The equation described the dynamics and conservation of momentum to simulate fluids. Many types of methods have been proposed in simulating fluid in

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CFD studies such as Smoothed Particle Hydrodynamics (SPH). SPH is mesh-free method which is firstly introduced to simulate astrophysical phenomena such as fission and star by Lucy (1997) and Gingold Monaghan (1977). SPH is also one of the most popular particle based fluid simulation vastly used in interactive systems such as computer games and computational fluid dynamic. The implementation of SPH in various fields can be seen in (Lui et. al, 2010).

Using SPH method for cardiac flow visualization is not new but rarely explored by the researcher. Based on work done by (Wang, 2009), SPH is proven to simulate pulsatile flow in the cardiovascular system with good reliability. It was first attempt to verify the capability of smoothed particle hydrodynamics. In real-time medical simulation, several papers has used SPH method in their framework of the system (Lui et. al, 2010) (de hoon et.al, 2014).

In the area of computer graphics and visualization, new fluid simulation techniques has been actively introduced until today. Advancement of computer technology is the biggest influences that encourage more advanced simulation techniques emerged to be used in real-time. Stam and Fiume have pioneered the use of SPH method in computer graphics area (Wladimir et. al, 2009). The SPH method was utilized to depict fire and other gaseous phenomena. In 2004, blood flow simulation using SPH was first time introduced by Muller (Muller et. al, 2004). The SPH simulated the blood flow of blood vessel in real-time for virtual surgery. Later, with introduction dedicated hardware such as PPU and programmable graphic processing unit (GPU) contributed other researchers to use improved SPH computational processes for blood flow simulation for fast development in training and virtual surgery (Pang et. al., 2009) (Sinnott et. al., 2006) (Pang et.al, 2010)(Jing et. al., 2010). Newest publications are more on focus on boundary management to manage the interaction of blood flow with deformable wall of blood vessel and heart (Kim et.al, 2014) (Nobrega et.al, 2014). Macklin and Muller has published new improvement to particle based fluid simulation of SPH by introducing an iterative density solver integrated into the Position Based Dynamics framework (PBD). Latest update on the particle-based system by using unified particle physics for real-time applications by Macklin open new opportunity for real-time application to improve rendering performance (Gerszewski & Bargteil, 2013).

Based on the latest survey done by (Koller et .al, 2016) on blood flow simulation using 4D PC-MRI data for data assimilation and verification. Assimilation of measured data used to increase understanding and improve visual analysis of hemodynamics (de hoon et.al, 2014). Simulated CFD and measured result verified to show the significant difference between both. Measured data coincide well mainly caused by limited spatial resolution.

Physics based animation is among popular topic in real-time computer graphics. Physics based animation can be described as a field in computer graphics to produce physically simulation in interactive rate with plausible effect. In medical visualization, physics based animation has been implemented widely, for example, OpenTissue toolkit that integrates physics based animation with medical visualization under one toolkit (Erleben et .al, 2005). Every year new techniques emerged with more robust and more high-detail effect produced. Fluid simulation is an active topic in computer graphics. In context of medical visualization, many researchers has been utilized and update the new technique in physical based animation with considering the applicability of techniques.

Implementation visualization in a game engine can be seen in many articles. There are of the article focusing on to provide immersive for medical data (Quam et. al., 2015). Work on interaction with medical in game engine still can be researched further in order to improve interaction with data in visualization.

Blood Flow Simulated Data for Vascular Structure

Blood flow simulation involving two major steps (Vilanova et. al., 2012). First, the vascular structure has to be segmented, and the geometry of the vessel boundary measured as accurately as possible. Next, a Computational Fluid Dynamics (CFD) model simulates the blood flow within the reconstructed geometry. These simulation data can be processed by available libraries such VMTK and SimVascular that extract data from medical images and support computational hemodynamics that focuses on vascular structure. Fig 1 shows example simulation produce by SimVascular.

File generated by the simulation library is saved in vtp and vtu file that can be viewed in Paraview. There are three results generated in this simulated data which are velocity values, pressure values and

other hemodynamics quantities such as wall shear stress (WSS). This research will start by extract velocity values to be loaded in 3D game environment. A loader will be developed so these data can read

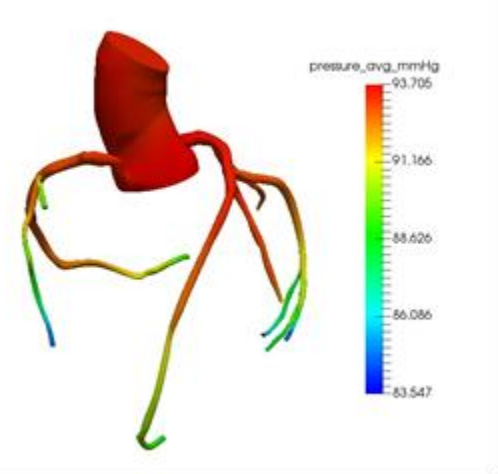

Fig.1 Average pressure from coronary simulation (SimVascular, 2017).

Visualization Techniques

MegaFlow is a package that allows you to use Vector Fields data to control the movement of objects or particle systems in Unity. Vector field data are a 2D or 3D grids of values that describe the direction and magnitude of velocities for that point in space. The Vector Field is data generated by SimVascular. Fig 2 shows the sample visualization of vector data using MegaFlow package. This system will be customized in order to produce an integrated algorithm for vector field data and physic-based animation technique.

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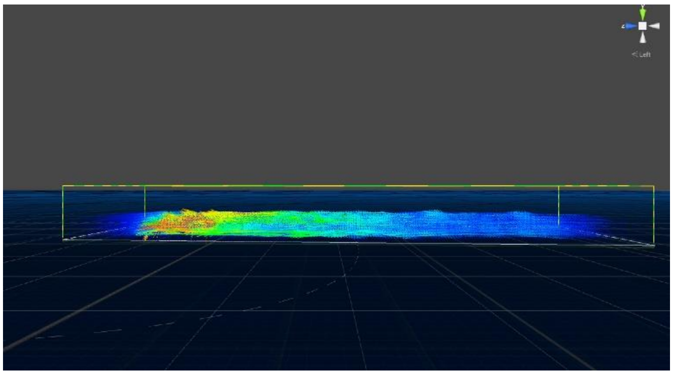

Fig. 2 Example visualization vector data for Unity.

Integration Framework for Interaction

This framework is introduced to integrate scientific visualization and physical-based simulation technique for blood flow visualization in small vascular tree structure from large arteries to show complex correlation between vessel geometry and blood flow visualization technique for robust interactive application. In this activity, centerline and cross section of vascular will help fluid simulation to be more optimized. In the next stage, the blood flow physical information are simulated and decomposed into particle-based flow. These particles will allow to simulating coronary artery blood flow rendering. This particle-based fluid simulation method will also allow the simulation done in real-time. This framework is based on worked done by (Quam et.at., 2015)

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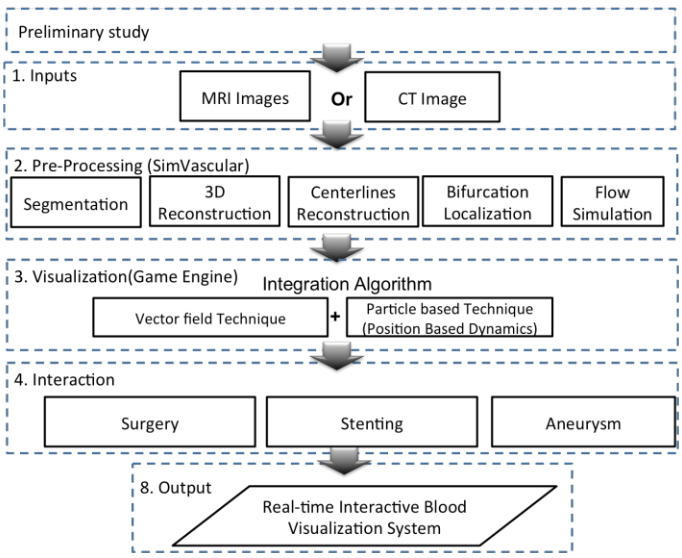

Fig. 3 Framework of the research.

Physical-Based Animation Technique

In our implementation, the interaction between fluid particles and blood vessel implemented by converting 3D mesh of extracted vessel into soft body object that represents by particle representation. Soft body objects is created by load Wavefront Object (.obj) file directly that originally created by SimVascular. By converting it into particle based representation, the blood vessel will be deformable objects.

Fig. 4 shows the initial visualization of blood flood tested on abdominal aorta arteries. The 3D mesh of blood vessels was represented by cloth object that automatically generated by position based dynamic as it loaded into the program. At that figure, the stream of blood will be represented by vector field technique. The application of algorithm still unfinished because it needs modification so the shaping matching technique can fit the model.

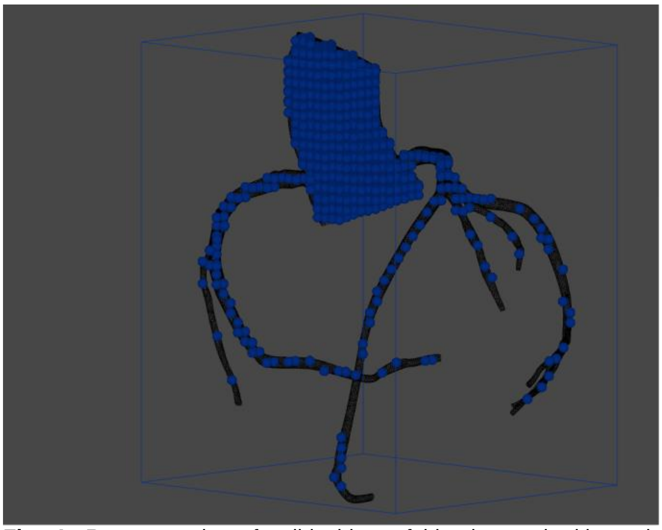

Fig. 4 Representation of solid object of blood vessel with particle-based technique in Unity game engine.

CONCLUSION

The framework of this paper will contribute to the visualization and also a simulation of blood flow in real-time. By using particle based physics to provide the opportunity to develop interactive blood flow visualization in the vascular tree in easier implementation. The proposed position based dynamics technique is implemented to the interaction of physically blood flow visualization in vascular tree. The process involves several processes: reconstruction of CT images into 3D, boundary management and position based fluid flow solver with integrated coupling solver method for fluid-object interaction. Modelling the geometry of vessel requires us to select the region of interest to be used with generated centerline as guided for 3D the vascular tree model. Suitable physics based algorithms will introduce help to reduce the computational cost to visualize of blood flow in vascular tree network. However, the result of the research still not be achieved especially assimilation algorithm with measurement data. Future works include the development of medical-related simulation system such as pre-surgery evaluation, stent installation simulation and also serious gaming for training purpose.

ACKNOWLEDGEMENT

This work was financially supported by the Universiti Teknologi Malaysia under the Research University Grant and Ministry of Higher Education Malaysia and eScienceFund from Ministry of Science,Technogy and Innovation Malaysia with reference number R.J130000.7928.4S135.

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