A Multimodal Virtual Anatomy Learning Tool for Medical Education

Ponnampalam Gopalakrishnakone[*] , Lu Jianfeng[+] , Goh Poh Sun[*], Asanka Abeykoon[^]

Owen Noel Newton Fernando[^], Adrian David Cheok[^]

[*]Yong Loo Lin School of Medicine, National University of Singapore

119228, Singapore

[+]Dept. of Computer Science & Technology, School of Computer Science, Hangzhou Dianzi University

310018 ,Zhejiang P. R. China

[^]Keio – NUS Cute Center, Interactive and Digital Media Institute, National University of Singapore

119613 , Singapore

ABSTRACT

Computer-aided learning (CAL) has great potential in facilitating learning. In medical education, several approaches using CAL have been used. In this paper, we present a novel software platform which we developed to provide a virtual learning environment to support anatomy teaching and learning. This learning platform provides accurate, interactive models which are derived from actual CT and fMRI scans. The virtual 3D environment is particularly useful to help students identify key anatomy structures and their complex spatial relationships. The intuitive computer graphic interface and virtual reality 3D environment make learning interesting and engaging. The platform also allows instructors to easily customize the anatomy model by adding additional digital supplementary learning material including hyperlinks, images, animation, audio, video, and PowerPoint presentations which are all supported within the platform.

Keywords: Virtual Learning environment, Medical education, Direct volume rendering, 3D Graphics, Multi Touch Interface

1. INTRODUCTION

Anatomy is one of the most important subjects in the core curriculum and potentially difficult to learn, particularly relationships between adjacent structures. In the past, medical students learned anatomy by reading text books, studying labeled illustrations in atlases, and participating in the dissection of human cadavers [6]. It is clear that a 3D learning environment can improve the understanding of complex structures and spatial relationships.

With the rapid development of the computer-aided technologies and three-dimensional graphics, several strategies using CAL have been applied in medical education [1][2]. Virtual reality learning environment (VRLE) is a powerful technology and has been applied successfully for teaching and learning in the medical anatomy curriculum [3][4][5]. In VRLE, the students can interact with the 3D anatomy models created by computer. They can explore, navigate, and manipulate the virtual anatomy or focus on a certain structures in a natural and intuitive way specially by using large touch screens. The virtual 3D models created from real human body offer more powerful capabilities in representing anatomical relations, and have been shown to be better compared with traditional methods[7][8].

In this paper we have proposed a platform provides accurate, interactive anatomy models for interactive teaching and learning. The intuitive computer graphic interface and virtual reality 3D environment make learning interesting and engaging. The platform also allows instructors to customize the anatomy model by adding additional digital supplementary learning material such as text, hyperlinks, images, animation, audio, video, and presentations which are all supported within the platform. To make use of online and mobile learning function, the system provides interface to extend online and mobile learning.

This paper is organized as follows. In Section "Related Work", we briefly review previous research using CAL in medical education. Then the design process of our platform is detailed explained in Section 3. In Section 4, the features of the developed prototype and some initial evaluation results are listed. The conclusion and future work are discussed in last Section.

2. RELATED WORK

There are many research publications describing the use of CAL in medical education. The early research work started in the late 1980's. In 1991, Satava created the first abdominal-surgery simulator comprised by images of organs. It supported a simple graphic interface program[9]. In 1993, The University of California, San Diego (UCSD) School of Medicine set up a project "VisualizeR" to assess a Virtual Reality (VR) system for anatomical education[3][4]. It provides 3D models of human anatomy in a VR environment. Some models in VisuzlizeR system are derived from National Library of Medicine's Visible Human Project dataset and others are created by their in-house 3D modeler illustrator[10]. In "VisualizeR", 3D models are all simplified and the quality is not very high restricted by the performance of the VR system they used. The system supports VR device input and creates an immersive environment. The effect of the VisuzlizeR looks good but the cost of the whole system is high.

Bundit has developed a new VR system with 3D touch sensitive input device for medical education[11]. The users can acquire the information of the virtual brain intuitively by touching the surface of the device. The Pittsburgh Supercomputing Center has developed volume browser(PSC-VB) in 2002[12]. The browser supports interactive navigation through the Visible Human datasets. This tool provides some labeled anatomical bookmarks for education purpose. The strength of the PSC-VB is it provides full body dynamic navigation through Visible Human data and display real voxel data of arbitrary cutting plane. But PSC-VB only supports a limited range of teaching materials. Another area of research in this field are the digital atlas development, including annotation and labeling of the anatomy structures[13].

One widely used anatomy educational software is the online 3D model of human anatomy of Primal Pictures Ltd[14]. This provides anatomy structures of the human body with text, pictures, and 3D models. The software is web based with a simple user interaction interface. The users can rotate and zoom interactively images of the models. The software however does not support real-time rendering and the interactive style is not intuitive.

Ideally, a good computer aided learning tool for medical education must support necessary course materials and intuitive user interaction. The cost of the learning system should also be low. In this paper, we present a software platform which we have developed which provides a virtual learning environment to support anatomy teaching and learning based on the desktop computer with large scale multi touch screens. This system also allows many course materials such like text, image, animation, audio, video, and presentations to be supported in the learning system. The 3D learning environment provides a user friendly interface allowing users to manipulate anatomy models in real-time.

3. SYSTEM DESIGN AND IMPLEMENTATION

3.1 Data flow

The project is mainly divided into two parts: High quality 3D models creation from the real CT dataset and the designation of the 3D learning software. In first stage, our work focuses on the segmentation of the structures in CT dataset and the reconstruction of the labeled slices. We choose 3D slicer as the segmentation tool because it is a multi-platform, free open source software, and most suitable for our project[15]. It provides many good segmentation algorithm and friendly user interface. The other advantage is that it provides source code so we can modify the program and add our new algorithm into the system. The data flow of the project is illustrated in figure 1. Firstly, some filtering methods are applied to remove the noise in the slices. Then organs in the chest are labeled with different colors interactively. Finally 3D models are created with the reconstruction algorithm. The whole process is semi-automatic and user interactive.

3.2 System Architecture

The software framework supports integrating 3D anatomy models with digital material in other formats e.g. video, audio, animations, presentations and hyperlinked text. The software also has an interaction interface so that teachers can add and modify the course materials in the 3D models according their teaching requirements.

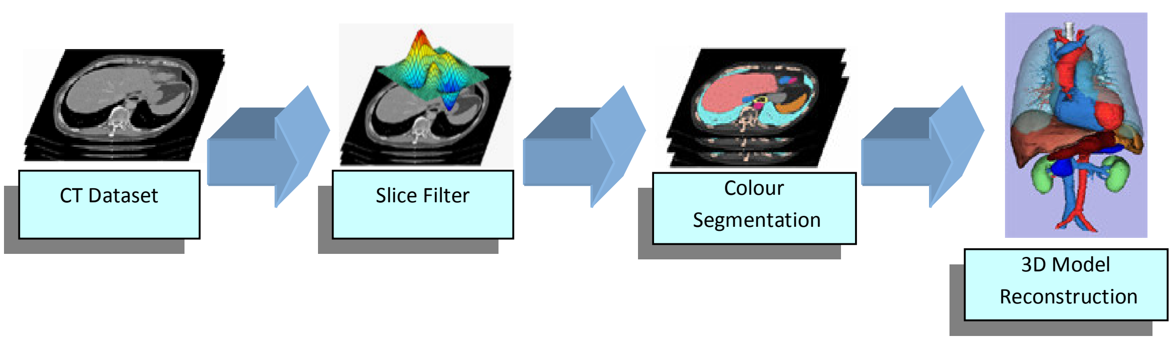

Figure 1. The extraction process of anatomy models

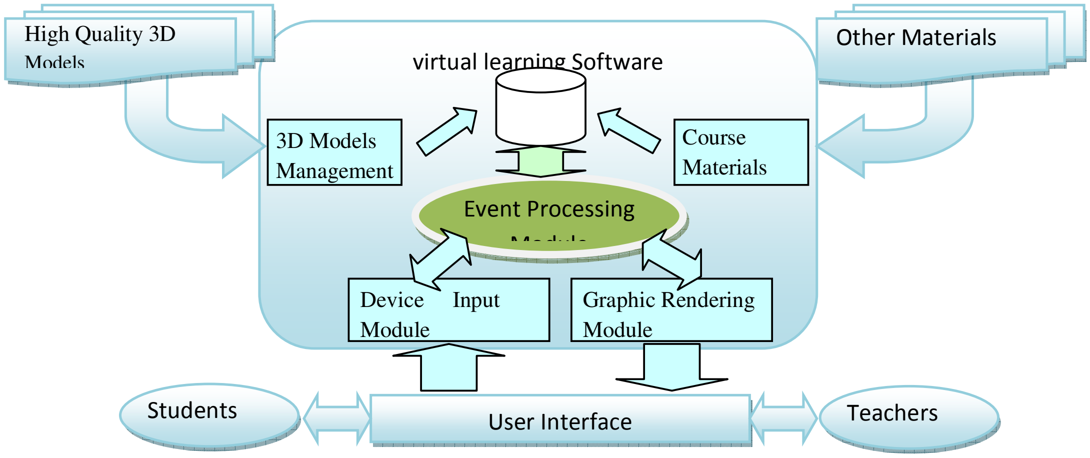

Figure 2 Software framework

Medical students can then use the software to browse and explore the human's body structures in a virtual reality 3D world. Teachers can easily customize the software if they want students to focus on certain anatomy or part of a structure. And also they can label and annotate structures with various media like text, image and video etc.

To obtain the high performance and flexibility, we choose Visualization toolkit (VTK) as the class library in our software developing. VTK is an open source software developing toolkit for 3D computer graphics, image processing and visualization used by thousands of researchers and developers around the world. It supports a wide variety of visualization algorithms for medical image processing [16].

The system architecture is illustrated as figure 2. There are five main modules in the platform: 3D models management, course materials management, event processing module, device input and graphic rendering module. The event processing module is the core part of the framework. It processes the events of the input device, manages the whole 3D scene and renders the images according to the users' interaction. The input module is designed to be convenient to attach other input device like touch screen or other input device.

3.3 Masked Volume Rendering Technique

Volume rendering is the powerful technology to display the precise organ structures [17][18]. It is accurate but time consuming. To overcome this weakness, we proposed a new masked volume rendering approach support partial volume rendering. The basic idea of masked volume rendering is to render the partial volume data obtained from the clipping part using labeled models. The software supports mixture rendering of the surface and volume data. In normal organ structure, we use high quality 3D models to render, and the masked volume rendering is applied in the structures needed more accuracy or difficult to model. The idea of the masked volume rendering is illustrated in figure 3. Firstly, we define some spaces: the color label space V_{label}, illustrated as (a) in figure 3, CT data volume space V_{ct} as (b), masked volume space V_{mask} as (c). The relationship of three spaces can be written as following equation (1).

$$V_{mask} = V_{label} \otimes V_{ct} \tag{1}$$

We use direct volume rendering technique (DVR) to render the data after we get the masked volume. The rendering result is show as (d) in Figure 3. Compared with 3D model rendering, Volume rendering is more accurate and realistic.

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3.4 Multi-platform extension

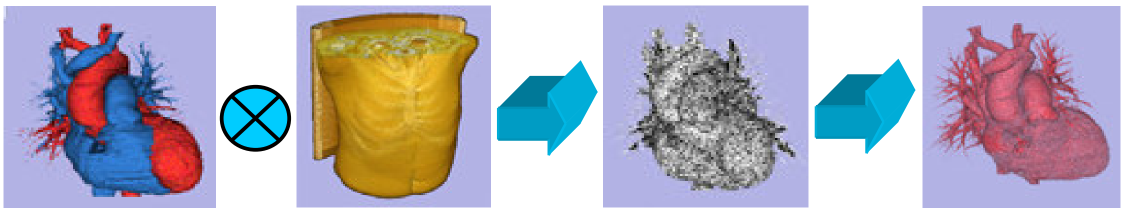
To make use of the benefits of the online and mobile learning function, we make an interface for web extension and windows mobile platform phone. Based on the web 3D technique, the virtual learning environment is created on the web browser. The users can interact with the anatomy models. To speed up the performance, system cache is adapted in the framework. When users first access the system, the models are stored in the local cache of the user's computer. So when the users access the system next time, the waiting time are much reduced. The figure 4 is the snapshot of the prototype system.

3.5 Multiple Disciplines

The System can be easily configured to use with other disciplines such as physics, engineering, architecture, geography ….etc where 3D models are crucial in teaching and learning. In case students and lectures can add relevant 3D models and can attach multimedia contents in to the system. After properly configured, users can explore the 3D structures and multimedia content with gestures.

3.5 Multi-touch interface

Multi touch interaction technologies used in most recent interactive learning applications which provides better experience for users. In addition to that using multi touch interface, multiple users can interact with system simultaneously with the virtual models which is not possible with the traditional learning applications. Having such system Medical students are able to use the system to browse and explore the human's body structures through virtual reality with hand gestures very easily and teachers will be able to easily customize the Software if they want students to focus on certain anatomy or part of a structure. They can also label and annotate structures with various media like text, image, animation, video, power point presentations. The students can browse these structure models like they are really in a virtual world. They can rotate, zoom in/out, or show part of the models, and focus certain parts of the anatomy for their leaning process. The figure 5 illustrates snapshot of the prototype system using touch screen.



(a) (b) (c) (d)

Figure 3 Flowchart of the masked volume rendering

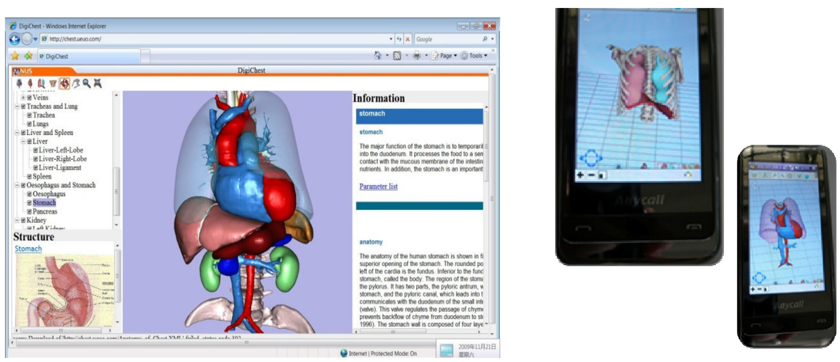


Figure 4: prototype of the online and mobile learning system

4. SYSTEM EVALUATION

We have developed this learning tool in C++ on Windows. There are no special hardware requirements and the software can be deployed to the normal desktop personal computer with similar configuration.

The main interface of the software is showed in figure 6(a). Left write part is the control bar of the anatomy structure and the right is the 3D scene. The figure 6(b) shows the interactive clipping process of the CT data. It is powerful to distinguish the space relationships of the different structures. The users are easy to associate the 3D models to the real pixels in the CT data. In figure 6(c) and 6(d), we demonstrate the effect of the mixed rendering of surface

and volume and the clipping process of the volume data. In last figure 6(e), It is a real structure of flail chest and pneumothorax. The different colors and shape contraction show the injury parts and the results in consequence to the users.

4. CONCLUSION

In this project, we have proposed a novel framework of the e-learning software and implemented a prototype system. It successfully integrates the 3D anatomy models and other course materials in the existing themes in the project. The software has the following features:

1. All 3D models are created using anonymised patient CT dataset. Key structures are selected based on core teaching content.

2. 2 .It's a 3D system so students can browse these structure models. They can rotate, zoom in/out, or show part of the models, focus certain anatomy. The user interface is quick, easy to use and intuitive.

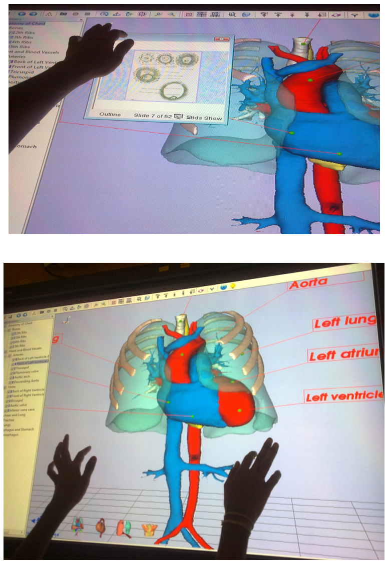
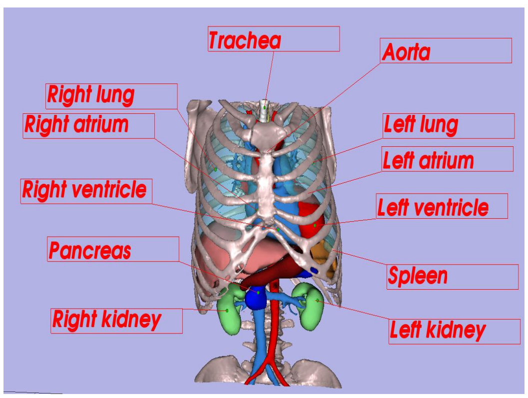


Figure 5:- Interacting with application using multi touch screen

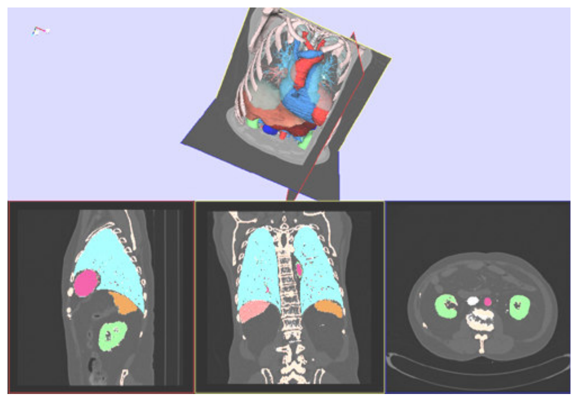
3 .The system can be freely customized according to the requirements of teaching staff and students. Multi-media course materials such like 3D models, animation, image and video may be added easily depending on teaching requirements.

4 .The system provide online and mobile learning interface, Collaboration "wiki style" to facilitate group learning or peer to peer learning is possible.

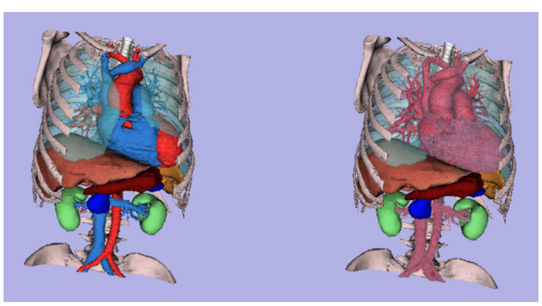
Currently the system is working fine with mouse and keyboard as well as large multi touch interface. It’s functional enough for teaching purposes and learning purposes. In future we are planning to embed the system in to a more advanced multi touch tables and provide more team based learning capabilities.



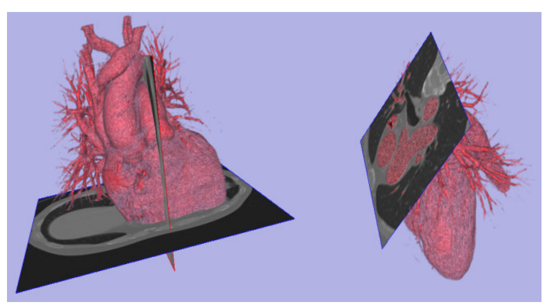
(a) Labelled anatomy structure



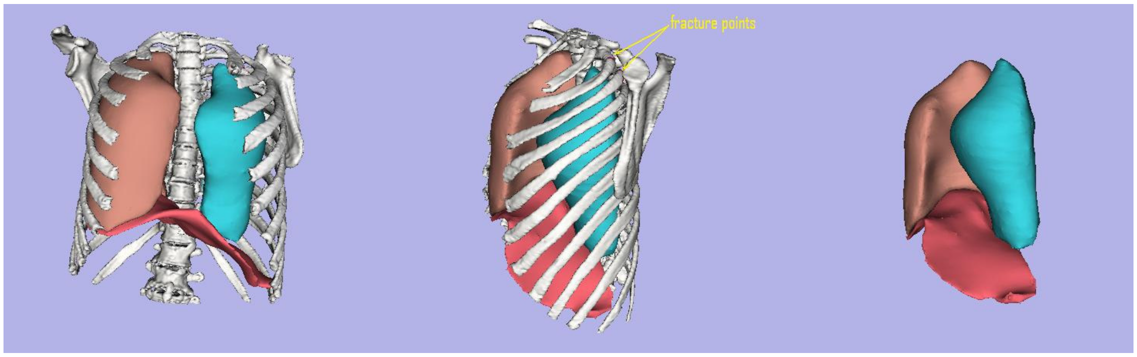
(b) extraction data by clip plane



(c) volume and surface mixed rendering



(d) arbitrary clip plane to volume data plane



(e) demonstration of flail chest and pneumothorax

Figure 6 : Experiment results

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