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Different Medical Modelling Strategies in a Single Collaborative Immersive Virtual Environment

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Abstract

Visualisation and simulation systems are becoming increasingly popular nowadays in medical planning and training. These tools are built using various technologies, such as computer graphics, Virtual Reality, and three dimensional (3D) modelling. The latter is an important element to these systems, because it governs how models are represented and how they can be manipulated. In this paper, we investigate the use of various 3D modelling techniques in a virtual immersive collaborative environment. We highlight the merits and limitations of these techniques, explain how they can be used in a virtual medical context, and demonstrate a practical application.

Categories and Subject Descriptors (according to ACM CCS): I.6.3 [Simulation and Modeling]:Applications

1. Introduction

Training highly qualified medical practitioners require the use of various forms of training procedures and materials. Training on cadavers, animals, and patients (in some cases)is one part of gaining expertise and knowledge. Studying textbook images and using plastic models is another. All these methods have their limitations. The use of cadavers and animals is expensive, inaccurate, and raises serious ethical and moral concerns, while two dimensional textbook images have their inherent limitations of obscuring valuable details. Training on patients is not desirable, because it exposes them to risks. Therefore, alternative training and planning methods need to be considered. Computer graphics in general and Virtual Reality(VR) in particular are promising to introduce alternative solutions to such requirements. VR technology together with three dimensional (3D) modelling, simulation, and visualisation techniques lend themselves well to the unique nature of medical procedures.

VR is an emerging technology, which can play a leading role in future surgery training, planning and simulating [OLS*95, LOSV94, LTCK03, VBB04]. Virtual three dimensional cadavers can be used to study anatomy structures and operation procedures. Trainee surgeons are able to practise procedures using simulation systems as many times as they require, without the need to put patients at risks or use controversial materials such as, cadavers. Surgeons can also plan their critical surgery procedures using their patients data before going to the operating theatre. VR systems also allow leading experts to operate on remote patients, offer advice, or help peer surgeons in geographically distributed locations. Collaborative visualisation gives medical experts the chance to share data and opinions remotely. Such tools and methodologies will eventually reduce risk to patients, reduce cost to health care providers, and enhance practitioners diagnostic and surgical skills.

For medical simulation systems to be effective, visual behaviours such as, tissue deformation, tissue dissection, suturing, and bleeding [Gib95, GSM97, MK00, BGTG03, Fri99] and haptic cues to simulate the sense of touch and force need to be included and modelled accurately. Visualisation systems also need to meet certain goals to gain access to information embedded in the visualised data. For example, it needs to be informative, effective in presenting significant features, act as a communication medium, and enhance understanding. 3D modelling is an important element of medical visualisation and simulation systems, because it controls how models are constructed and manipulated. In visualisation systems, modelling approaches control how much detail is required to visualise data. Factors such as, the purpose of the system and the nature of organs involved may dictate requirements on realism to organs, tools, or proce-

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dures. In simulation systems, however, there is a tight relationship between the actions performed within the system and the underlying modelling approach used. Techniques adopted usually govern how such actions can be simulated [CBR*99, BHS01, MT96, SCA, AR04, LTCK03].

2. Strategies of medical modelling

In general, models for medical applications can be represented geometrically by mathematical procedures or abstractly by basic shapes or primitives. Depending on the visualisation or simulation system requirements and applications, a different technique or a combination of techniques may be applied, each one of these techniques has its own limitations and merits as described below [KCY93, KC93, LKN*96].

2.1. Volumetric modelling

Volumetric modelling is a widely used technique [KCY93, KC93, GFG*98, KDC*00], where 3D models of human organs are generated from real human scanned images, such as Magnetic Resonance Imaging (MRI), Computer Tomography (CT), or Positron Emission Tomography (PET). The generated images are then displayed as high quality voxel-based 3D volumetric models. The main advantage of such a technique is the ability to preserve original anatomical structures and details from the acquired data, see Figure 1. Its main drawback is the need for powerful computational systems to compute the massive quantities of data involved. Such conditions will have serious implications on systems rendering speeds, Also, it requires high storage capacities to contain such huge data.

Figure 1: *Volumetric medel of the head.*

2.2. Iso-surface modelling

Iso-surface modelling (Indirect volume rendering) is another common modelling approach in medical visualisation and simulation systems [LKN*96, GBK*96, KBG*95]. Such technique involves the generation of interesting or relevant surfaces from volumetric data, Figure 2. A segmentation stage to extract the desired surface/surfaces is usually carried out before the final image can be generated. This process normally increases computational times and also needs highly qualified medical personnel who have good anatomical knowledge to extract the required structure from the volumetric data. Rendering speeds of such applications are normally increased due to the dramatic reduction in data size. Appearance of such representations can be enhanced by applying surface texture mapping of real images captured from real organs on the surface of the model. The high rendering speeds and the realistic appearance always come at the expense of a loss of valuable internal data, because only structure surfaces are shown.

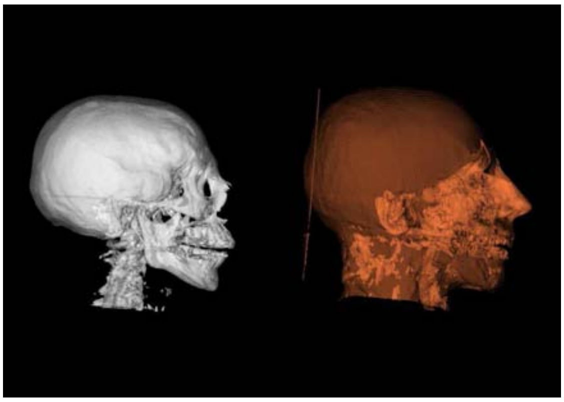

Figure 2: *Iso-surface models of the skull and head taken from a volumetric data set.*

2.3. Surface modelling

Polygonal or surface modelling is a technique that is widely applied in simulation systems. This modelling procedure is an artistic representation of models created by the developer. Models are composed of a set of polygons. The number of polygons used normally govern accuracy and smoothness of models. Surface representations are relatively fast to render, but this gain again comes at the expense of losing accuracy and detailed representations. Such models may also produce unrealistic results especially when thin tissue deformations are involved. Polygonal modelling is suitable to model flat or thin tissue types, such as vessels and the gallbladder [Del98].

The choice between surface, iso-surface, and volume based models is normally controlled by computer power and visual accuracy required as we shall see.

3. Requirements

In order to exchange experiences, get advice or feedback, offer assistance, and explain procedures, there is a requirement for methods and procedures to share such resources.

Medicine is a typical application of such scenarios. Participants may need to comment on shared models or actual patient's data. At a clinical level, medical practitioners may also wish to share data for diagnostic or counselling purposes. While at an academic level, sharing models can be an effective procedure in demonstrating anatomy structures to medical students.

Abstract and static data visualisation is not sufficient. Interaction and engagement with data is the ultimate goal. In the medical field, data representations could be used for diagnostic purposes, but they might also be used for simulating complex operational procedures. The task of simulation will require various forms of interactions and manipulations. Not only that, but object sharing and collaboration might be needed in certain cases. This introduces the need for interactive and collaborative implementations to share and manipulate models of different forms between different distributed users.

4. Medical potential

3D visualisation technologies provided the medical community and other disciplines with tools that make their highly demanding requirements within reach. Visualisation of 3D data sets contributed greatly in assisting clinical experts in many areas ranging from fracture identification to complex surgery interventions [OLS*95].

Being able to view models and objects in a 3D format is a bonus, but to be able to interact and manipulate shared objects in a 3D environment is what really makes today's visualisation techniques the road to tomorrow's expectations. VR is the focus of this era [LBF*01, RLL02]. VR not only allows users to view and manipulate virtual scenes locally, but different users in geographically distributed locations are able to interact and communicate in real time. Immersion, interaction, and collaboration are some of the central virtues that virtual reality provides. Immersion puts users in the middle of virtual environments and allows them to interact directly and closely with virtual objects. Such feature can be experienced in the Immersive Projection Technology (I.P.T.) CAVE (Cave Automatic Virtual Environment)[CSD93]. Interactivity is another significant element that makes visualisation and simulation systems more practical, because instantaneous changes can be activated by user actions within the environment in real time. Collaboration, however, brings together geographically distributed users, and allows them to share and interact with models in the same environment [BSX94, PBF02, BDGW98, WSWL02].

Such VR benefits can be applied to medical visualisation and simulation applications. Immersion is beneficial, because medical professionals are able to interact and manipulate their data closely to make more accurate diagnosis and examinations. Medical expertise and advice can also be shared via collaborative environments. While interactivity can enhance medical visualisation and simulation, because instantaneous responses are typical requirements in medical interventions. Looking at the different modelling methodologies and the valuable features of VR, we find it reasonable and appropriate to integrate such technologies to enhance applications in both medical visualisation and simulation fields. Later in this paper, we will introduce an application, that displays different modelling approaches in a fully immersive collaborative environment to allow remote and local medical researchers and practitioners to interact with models of their choice. The application addresses issues related to visualisation, such as the level of detail modelling as well as simulation operations like object manipulation and sharing. Different modelling approaches will be used to demonstrate how effective each technique is in immersive collaborative environments, and how they can be used for various types of medical applications.

5. The CAVE

The CAVE is a large cube shaped display medium that is composed normally of four special flat screens (three walls and a floor). CAVE sizes vary, but 10X10X10 feet is common. The CAVE may accommodate five to six users at one time who can move freely. Images are back projected on the screens by big projectors. Projectors for the walls are situated behind the screens, while that for the floor screen is suspended from the ceiling. To see images as stereoscopic 3D images inside the CAVE, users need to wear liquid crystal shutter glasses. Images are displayed according to the position of a prime user who is wearing a head tracking device. Via ultrasonic sensors, the tracking device sends its physical position in the CAVE to the rendering engine. Based on this position, images are computed, rendered, and then displayed accordingly. Other users than the tracking device wearer may see distorted images, because their positions in the CAVE are different from that of the prime user. Users are able to manipulate and interact with objects via a 3D-6 D.O.F (Degree of Freedom) mouse known as the "wand". The wand is the control device inside the CAVE, with which users can control the operation of their applications. Typical wand operations include navigation, manipulation and rotation. In the navigation mode, travelling can be simulated in the virtual environment, while the users are physically stationary. Rotation mode allows the user to rotate around objects, or rotate objects around him/herself. Manipulation operations normally depend on the application and its purpose.

6. Our application

Visualisation requirements and basic simulation operations were taken into account when building this CAVE application. Various models or data sets of the human body can by displayed using the different modelling techniques. This includes volumetric, iso-surface, and polygonal models. Volumetric models can be used for direct disease and structure analysis purposes, while iso-surface models can be used to display and highlight unique structures, such as a nerve, a tumour, or an individual organ. Polygonal models can be used where original details are not so important to the user, for example demonstrating the shape of a bone or an organ. Polygonal models can also be used to model artificial implants or surgical instruments and tools.

Local and remote users are able to interact with their shared models. This includes picking up models and moving them around the virtual environment. Such feature is crucial in medical simulations, because individual models or objects can be shared amongst users and medical intervention procedures can be demonstrated. Distributed remote users will also be able to share and manipulate models. Remote users are represented in the environment as avatars (human geometrical representations). Avatars will behave in the same manner as their remote users and resultant reactions will be shown in all environments. Audio connections can be established between the networked CAVE's, this allows direct communication and feedback.

Users are able to approach and grab their models using their wands, and use wand buttons to activate actions. They are also able to navigate through their environment and walk around their models. For illustration purposes, a virtual pointer is used to point at areas of interest. This pointer is also used to pick up objects or models. Grabbing and selecting models can also be carried out by bringing the wand in contact (virtualy) with the models/objects, then they can be manipulated. Clipping and scaling tools were also included to further examine models, especially volumetric data sets. These two functions can be activated via a floating menu. The respective tool can be selected by the virtual pointer and then activated by pressing a wand button.To enhance volumetric models appearance, they are rendered with colour and opacity features, this also will help users to distinguish between the different tissue and structure types. Our application focuses on two key elements, the level of detail using different modelling approaches (volume, iso-surface, and polygonal), and the ability to manipulate and interact with individual models or objects. Both elements are important features of both medical visualisation and simulation systems.

6.1. Medical simulation and visualisation scenarios

Simple simulation scenarios demonstrating a hip replacement and a jaw structure and movement procedures were implemented. To simulate these tasks, the user does not require detailed models of the bones involved. He/she will only need to use polygonal or iso-surface representations of the bones in addition to the artificial implants in the hip replacement case. Relevant models and implants then can be grabbed and moved around.

In a visualisation session scenario, the surgeon may require to study and diagnose the ligament and bone structures of a patient's knee. Volumetric or isosurface model/models generated from the patient's scans are then required for this task, Figure 3. Surface representations will not be suitable for this examination.

Figure 3: *Examiing an iso-surface model of the knee taken from a volumetric data set.*

In another visualisation scenario, the physician may want to diagnose a brain tumour. In this case, he/she is interested to see a detailed model of the patient's brain data set to see how far the disease has advanced. Volumetric model of the head is needed in this case as shown in Figure 4. He/she may also need an isosurface model of the brain to analyse the size of the tumour, Figure 5.

Figure 4: *Examining a volumetric model of the head.*

7. Primarily findings

Collaborative tests had been conducted using this system between two CAVE installations located at different geographical locations. Local and remote users were able to interact

Figure 5: *Examining a volumetric head, togther with an iso-surface model of the brain.*

with models and objects independently. Interaction and manipulation tools were used to visualise and investigate volumetric, isosurface, and polygonal parts of the human body. Simple simulation tasks such as demonstrating a hip replacement procedure was also carried out.

Various volumetric data set formats can be loaded by the system, including the standard medical scanning format DICOM and others such as, TIF/TIFF, RAW, and IFL (Image Format Library). Volumetric formats are limited to these, because the current version of Volumizer library only loads these types, other formats can be loaded if tailored loaders were written for them. This functionality will be added in later versions. Polygonal formats such as, obj, 3ds, iv, VRML(wrl), and many others can also be loaded.

The focus of the application at this stage is the use of different modelling techniques in a single immersive collaborative application, and be able to manipulate models or objects interactively. Feedback from users suggests that such an application demonstrated the potential use of such strategies in medical visualisation and simulation systems. Based on feedback from users and our observations, we have identified the following benefits of such a system:

- Integration of different modelling techniques in a level-of-detail approach enhances application performance and data perception.
- Distributed users (local and remote) are able to examine rich medical volumetric data structures easily and closely to understand and study the impeded details.
- Medical visualisation and simulation applications can be improved using virtual immersive technology.
- Collaboration, object manipulation, and object sharing can be enhanced via immersive mediums such as, the CAVE.
- This application can be used as a standalone system, or connected to other installations to conduct collaborative sessions.
- Detailed volumetric modelling can be valuable for diagnosis purposes, while less detailed modelling (iso-surfaces and polygonal) is ideal for demonstrating tasks and structures.

8. System performance

System performance mainly depends on the file format used and how big the model/models are. It also depends on the computation resources available to local display. A volumetric model of size 608.5 KB permitted interactions at reasonable responses. A delay of less than a second was achieved, which made interactions easy and natural, although these interactions were only limited to grasping, clipping, rotating, and scaling. Models were loaded at both systems and each machine was started with a full copy of each model to prevent long transfer times during trials. However, dynamic partitioning and pre-loading can be employed for distribution of larger data set models.

8.1. Implementation tools

This application was built on top of the free networked Performer [OP05] based Coanim (the Collaborative Animator) [TEVL05] system. Various visualisation and rendering tools have been imported into the system to take advantage of their features. Performer is used as a common platform to implement the main application structure and graphic routines. Performer was chosen, because it provides a number of features that are significant to our application. This includes the high graphics performance across different SGI platforms, the efficient use of multiple processors with transparent multiprocessing, real and run times debugging, fixed frame rate for immersible applications, the feasibility to load various data formats, and others. CAVE routines were implemented using the CAVELib [CSD93] library. This library enables the system to track and update the application with user's position and wand actions. Based on these input values, the rendering routines update the displayed images. Volumetric rendering was implemented using the OpenGL Volumizer library [SGI05]. This library was selected, because it hides the details of graphics rendering from the developer and exposes only the functions that are needed to render volumetric data sets. Other features, such as high performance, ease of use, multi-pipe capability, and cross platform support made Volumizer a significant candidate. Iso-surface rendering was generated by the integration of the Visualisation Toolkit (VTK) [SML98]. VTK was chosen, because it takes the burden of programming away from the developer. VTK can also be run on different platforms. It also supports features such as, polygon reduction and textures. Networking routines were implemented by using CAVERNSoft [LJD*99, PCJ06], which is originally embedded with Coanim. CAVERNSoft has been selected, because it had proved to be a powerful platform to create tele-immersive applications that cover a large number of domains and applications [LJD*99, EVL05], it also has the capability to support the development of collaborative networked applications for VR displays.

8.2. System hardware

Our application was mainly run and tested on a four wall 10X10X10 foot CAVE installation at the University of Reading. The system is powered by SGI machine running IRIX 6.5.15m, which is supported by four 195 MHz R10K and eight 400 MHz R12K CPU's and 2 pipe Onyx Infinite-Reality2 Graphics with 64 MB texture RAM. Each pipe is responsible to render a pair of walls. Two KONAL graphics cards are used, one has 8 channels of display and the other has 2. Main memory size holds 5120 Mbytes, while instruction cache and data size are 32 Kbytes each. Networking communications are handled by two 10/100 Fast Ethernet cards. Collaborative experiments were carried out with another 10X10X10 CAVE at Salford University, UK. This installation is powered by an SGI Origin 2000 using IRIX 6.5.15m, which is supported by twelve 250MHz R10K CPU's, Infinity-Reality2E with four pipes, 64 MB of texture memory RAM and 4GB of main memory.

9. Conclusions

We have presented the integration of various technologies such as, 3D modelling, volumetric rendering, visualisation, simulation, networking, and virtual reality in one application. We have seen how such technologies can be used to serve training, simulating and planning in medicine. The focus of the system was to use various forms of modelling techniques to demonstrate different types of medical procedures in a common collaborative application. A level of detail approach can be a valuable strategy in meeting the overwhelming demands of medical visualisation and simulation procedures. Collaboration and object manipulation are some of the issues that have been covered. The system is not complete yet and still in a development stage, and further improvements need to be considered. These improvements may include the addition of dynamic medical simulation procedures, such as deformations or cuts. Formal evaluation by medical experts is required to see how far this system can meet their demands, and highlight benefits and limitations from the medical community point of view. Object sharing and networking issues will also be the focus of future implementations and studies to see how they can be effective in such system, and how they can be enhanced.

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