Real-time Simulation for Restorative Dentistry Procedure

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Abstract

Virtual reality (VR) is the human experience of perceiving and interacting with a synthetic environment containing simulated objects as if it were real. VR technology can be applied to many tasks that would be more difficult to do by other methods. This paper discusses the potential use of VR to producing an interactive-simulation for the Class I procedures for the cavity preparations of restorative dentistry. Analysis showed that Class I cavity preparations necessitate a range of motor, perceptual and cognitive skills. The objective is to produce a highly reliable training material that imitates the actual procedures of the cavity preparations. This project is seen as having the potential to add new dimensions and offers vast possibilities to improve not only the teaching methods but also diagnosis and the treatment planning processes.

Keywords:

Virtual Environment, Virtual Reality, Simulation, Dentistry, Restorative

Introduction

Simulation may be defined as the process of modelling a system in such a way that the model mimics the response of the actual system to events that take place over time [1]. Therefore a simulator must respond to events over time, in a realistic manner. During the last decade, volume graphics and scientific 3D visualisation have emerged as a major computer based technology [2]. VR is seen as an intelligent medium as it can imitate actions and behaviour of the physical world. One important characteristics of a VE is the real-time interaction (or near real-time), a user is able to perform changes and the computer is able to make the changes in the VE accordingly and spontaneously. This emerging technology is able to give attribute to 3D objects as well as its environment to react and change instantaneously.

Virtual Environment (VE) is a capable avenue for dental training just as they have been effective in other forms of medical training. It is a versatile medium for performing experiments to elucidate the basis of skills in dentistry. This paper proposes techniques for extending such VE to include the restorative dentistry procedures. This paper will also discuss the potential use of VR for web based dental learning simulation. User may interact in real-time utilising the web based computer-generated drilling simulator. Techniques concerning the prototype development of the simulation are also described.

The commercial solutions for medical VR are beginning to appear but the acceptance is still in the early stage [1]. Despite the expensive use of available VR systems, web-based VR has the potential to provide a cheap with wide availability solution. This project is a test-bed and a cooperative effort between the School of Information Technology, University Utara Malaysia and the Dentistry School of University Kebangsaan Malaysia.

Application

Restorative dentistry is an aspect of dentistry that repairs dental caries. The prototype simulates the procedure of repairing a carious lesion on the occlusal or biting surface of a molar tooth (Figure 1). The student diagnoses the lesion, removes the carious tissue and restores the natural shape of the crown.

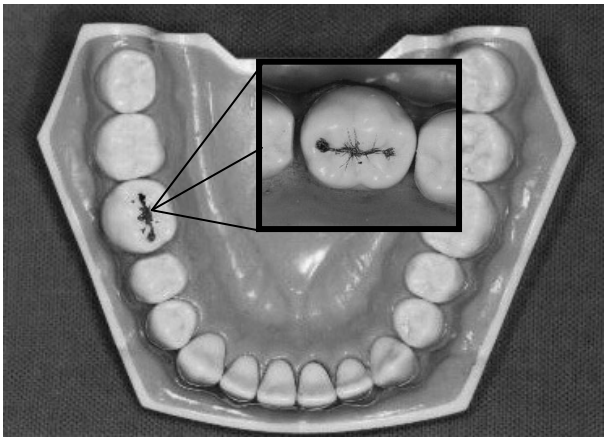


Figure 1- Condition of a molar with caries on occlusal

The goal of the procedures is to remove all dental caries and teeth damaged by dental caries. The form of cavity is governed by the amount of caries, by the structure of the

tooth substance and the physical and the chemical properties of the material chosen to fill it [3]. This simulation is aimed at training dental students with the necessary skills to restore Class I cavity. The successful completion of the procedure means that the decayed tissue is removed, the cavity is prepared and filled with amalgam and the tooth is restored to its previous natural shape and normal function.

Approach and Methods

Real time Web-based tool is being developed to create a low cost simulator to give students experience in manipulating objects in a VR world. The virtual display is designed to provide students with a simplified view of the component that they can rotate and view from other perspectives thus providing a more concrete visualisation. Additional information provided on the remaining displays applies directly to the virtual scene and supplements class instruction. VR gives the students a rare chance to initiate actions for them and to take control over aspects of their own learning [4]. Empowering students to be responsible for their own learning can be supported by carefully designed virtual environment. Developing this simulator involves specifying tasks and skills for Class I operation, generating 3D models, implementing appropriate user interaction and integrating VR environment with the web page.

Tasks & skills specification

The initial stage of developing the virtual environment requires identification of tasks and skills to perform the operation. Figure 2 shows a list a complete Class I restorative tasks and tools involve in each task. This is not a standard method to perform Class I course of action. But what presented here are basic tasks and tools required to perform the procedure. An observation has been conducted to investigate skills that a dentist should have to complete the Class I cavity preparation. The classifications are based on cognitive skills required to perform each tasks. Understanding how dentists perform complex tasks can guide the development of the VE and suggest which elements of the simulation are necessary for effective training. The identified skills to be possessed to perform Class I procedure are listed as follows:

Representational Skills

The basis for a correct clinical appreciation is a global understanding of the patient's clinical state [5]. Table 1 clearly shows that human vision plays most important role in passing information to the human brain and contribute to the human attention. Representational skill refers to an appreciation of the process or object, which improves the performance of the task. In this application the residents need to be trained to gain this skill to view the shape of the caries and perform correct clinical assessment. Performance

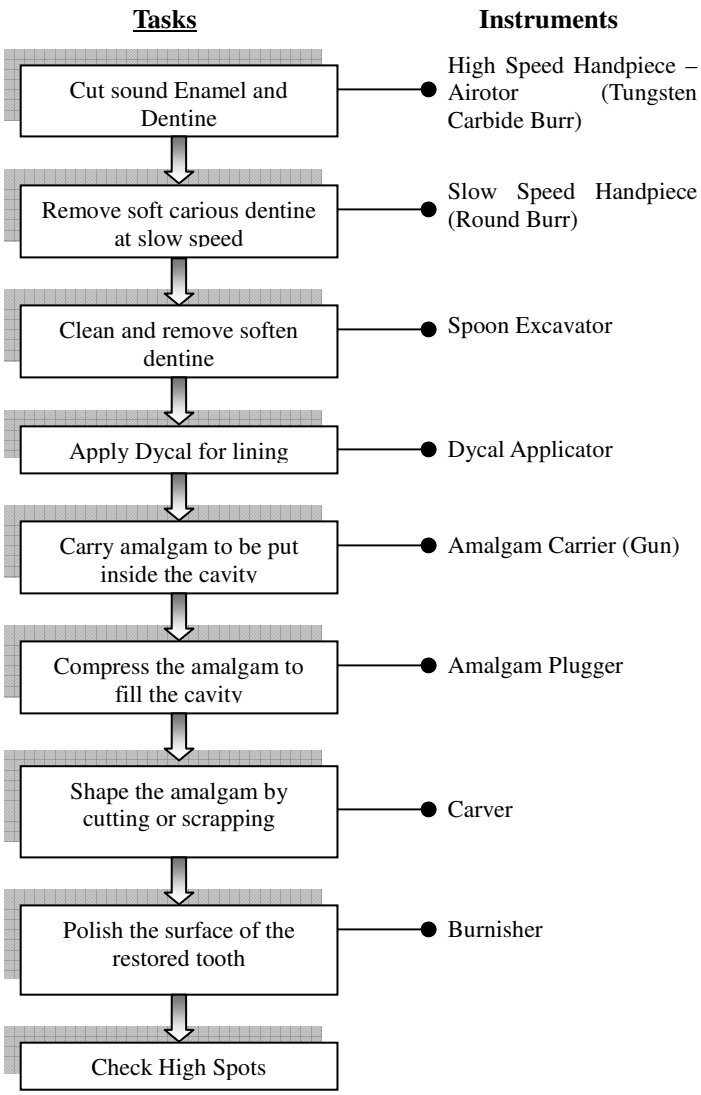


Figure 2 -Tasks and instruments of Class I restorative Procedure simulated in the virtual environment.

of this skill depends on the accuracy of the dentist's mental model of 3D geometry of the environment. Clinical assessment is a crucial process before an operation can be carried out. Therefore representational skills need to be tackled in order to create a good appreciation of the procedure.

Sense	Percentage
Sight	70%
Hearing	20%
Smell	5%
Touch	4%
Taste	1%

Table 1: Percentage of human senses passed to the human brain [6]

Procedural Skill

Procedural skills involve both cognitive and physical activities to perform a series of manoeuvres. This type of skill is learned by acquiring the basic knowledge first using didactic verbal methods supplemented by practical demonstration. This skill requires students to be acquainted with the steps or procedures that should be taken to complete the tasks. Apart from that this skill also demands the trainee to choose the correct type of instruments for different stages of treatment.

Decision Making Skills

One of the most important human skills is decision-making (judgement and choice) [7]. Decision making skill is a vital skill that a dentist must possess. Proficiency in making a decision can help to perform suitable diagnosis and treatment planning processes.

Psychomotor Skill

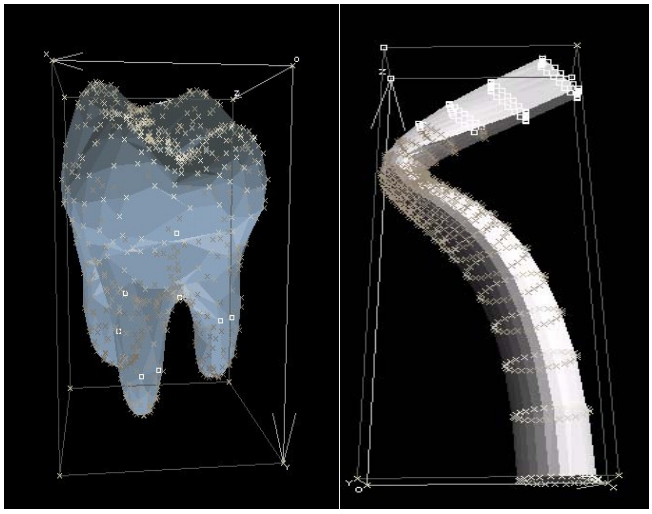
Dentists rely on touch feedback from the tool tip for diagnosis and positional guidance during the procedures. This requires psychomotor skill, which is defined as a skill where movement is based on kinesthetic cues. The skill can be transferred by tactile media, which translates situations like hitting the surface of the tooth (enamel) into haptic feedback. In order to include such feature a special input/output devices are required. However, for web based VR solution, only usual interaction peripherals (mouse and keyboard) can be delivered.

3D object modelling

After specifying all the requirements needed to perform the operation, it must now be put to view. To provide a meaningful educational experience, a dental training simulation must depict the relevant anatomy and dental tools as accurately as possible. All 3D objects are created using 3D modeller software. As realism is a very significant aspect in this simulation, the models are made based on imitation of the real objects. The size of the models is a major factor for both download and rendering times, as these can be large. Thus, it is important to ensure low polygon counts for each modelled objects.

Object Behaviour

Each objects and scenes exported to the VE will be given behaviour. The objects created are in a *.wrl file format which is a VRML (Virtual Reality Modelling Language) file extension. This means that the type of objects created are surface models. Since the models are not solid, the process of creating cavity by means of drilling, carving and scraping are prepared on dynamic vertices. The surface of the tooth is made dynamic by defining its vertices to move at a certain degree when the tip of tools hit the tooth's surface (Fig.3). All virtual dental tools' tip surfaces will be preserved from dynamic vertices.



a) b)

Figure 3- (a)Vertices on tooth's occlusal area selected for dynamic deformation and (b) tip of the trimmer preserved from dynamic vertices.

Interaction

The virtual world provides both a didactic and an experiential learning and training environment. A demonstration mode could give a tour of the intended subject and an exploration mode would allow the student to actually experience the environment [5]. Based on the skills analysis and the technology review, this simulator is divided into two modes namely a demonstration mode and a hands-on learning mode.

The user interaction has been designed to be used on a desktop computer utilising a non-immersive virtual environment. In creating a user friendly environment, the interaction of the objects are designed to be manipulated in a drag and drop manner. The objects can be moved around by clicking on it and drag around the world using a mouse. As the application runs on WWW platform, the user interface is created to allow interactivity both on the web and the virtual environment.

Web page and VR Integration

There has been a growing interest in exploring the utility of the web environment in simulation applications. According to [5], this interest can be classified into two main approaches. First, perform the simulation task on the server and present the result on the client side. Second, execute the whole simulation process on the client side, where Java applications and applets are utilised. These systems typically have visualisation processes (pipeline steps) statistically mapped either all on the client side or on the server side (while the client displays the resulting 3D scenes) [8]. (Fig. 4). Visualisation software publishing approach has been utilised for the purpose of Internet inclusion. Publishing visualisation software greatly reduces

the demands put on the server and has the potential for more interactive data exploration by tightening the loop between the user and the visualisation system [9].

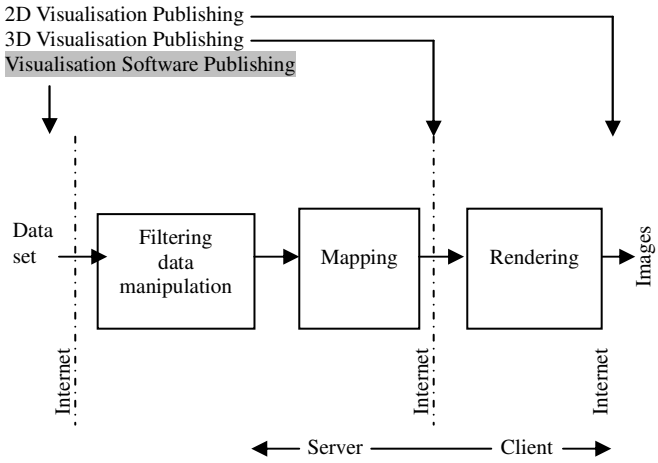


Figure 4 - The visualisation pipeline with the Internet [9]

The development of the simulation employed Fat client solution (most of the visualisation steps are processed at a client workstation). Embedding the virtual simulator on the web enabled large user communities to be accessed. Furthermore, this approach allows the simulator to run on various platforms without being installed locally. The system works by transmitting the software in advance and runs just like Java Applet within a web browser.

Results

The task analysis had been classified according to the cognitive skills required to perform each tasks. This analysis resulted in identifying two essential piece of knowledge: an application of the 3D tooth anatomy and skills needed to perform the operation. Based on the identified skills aimed to be achieved by Class I restorative procedure, it is concluded (figure 5) that an ideal restorative procedure simulator should include the following features:

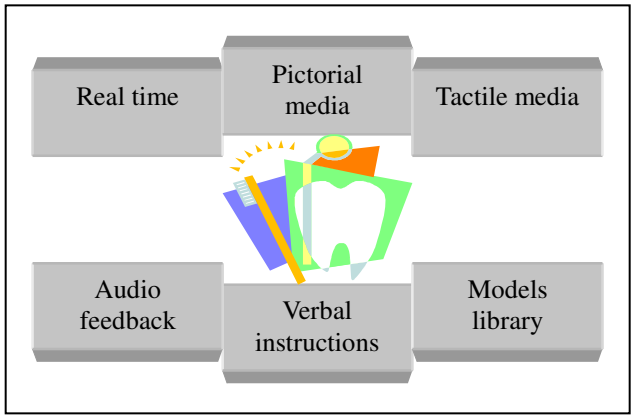


Figure 5 - Ideal components of a VR simulator for restorative procedure.

To manoeuvre the hand-piece and other dental tools, the operator must have a combination of eye/hand coordination and force perception. On the downside, restricting this simulator to the WWW platform makes it challenging to satisfy the realism criterion. The use of haptic feedback devices to form force perception is not yet possible on the WWW [10]. This is due to the fact that no standard browser supports any other devices. This feature can be replaced with an alternative sensation, namely audio and visual, in order to provide a partial support to this skill. The design of the 3D page (web page with 3D objects) has been optimised to include multimedia features (Figure 6). Though the web-based simulator is deficient in providing tactile feedback [10], the there are many important training goals that can be satisfied including:

- Improving the 3D awareness of dental trainee
- Enhancing knowledge of anatomical teeth structure
- Providing a media rich learning environment
- Increase the quality procedure and reduce the number of mistakes.

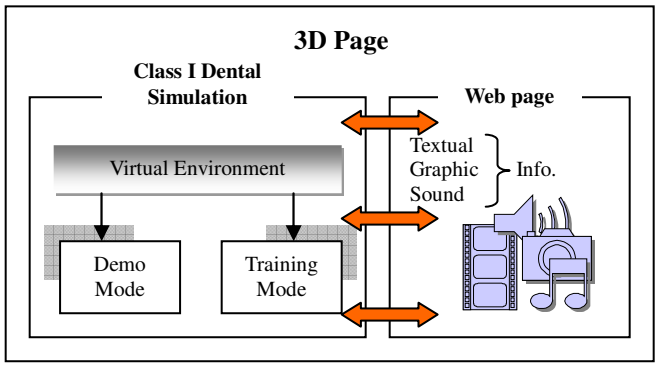


Figure 6 - Overall structure of the 3D page.

Discussion

The real time or near real time criterion as well as interactive attribute that VR system posses has made it applicable for large number of applications. The expensive paradigm of VR can be shifted to a more open, accessible and scalable solution by migrating it to the web environment. Providing a world wide access to this technology and building a platform independent VR applications has the potential to create an affordable and accessible solution. Likewise, its applications can be spread to a wider spectrum. The evolution in web technology has created a space whereby virtual environment can be embedded onto the web page. By adding dimensions and interactivity, information is obviously becoming more attractive and impressive.

Conclusions

Medical VR includes organ modelling, tissue cutting, programming toolkits, training in palpation, anaesthesia, surgery, rehabilitation and dentistry [11]. VE is a capable avenue for dental training just as they have been effective in other forms of medical training. However, if VE is to

achieve its' potential in dental training; there are two major areas of research needed. Firstly, the technicality aspect of the simulation; the dynamic modelling of mechanical behaviour of material removal during cavity preparation and restoring the teeth with restorative materials. The second need is the development of a better understanding of the basis of procedural skills in restorative dentistry. There has been very little research effort toward understanding the perceptual-motor and cognitive processes that contribute to the training performance. Virtual environments are a versatile medium for performing experiments to elucidate the basis of skills in dentistry.

Dental training in virtual environment has many potential advantages. It is interactive, yet an instructor's presence is not necessary, so students may practice in their free movements. The ability to understand multiple perspectives is both a conceptual and social skill; enabling participant to practice these skills in the way that cannot be achieved in the physical world may be an especially valuable attribute of VR [10]. Any disease state or anatomical variation can be created. Students can try different techniques and look at anatomy from perspectives that would be impossible during training on physical phantom head.

The exponential growth of the World Wide Web (WWW) has made possible of the data exchange and services. Now the WWW platform has the ability to widen its applications by allowing distributed simulation application to be put across the net.

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References

[1] Soferman, Z. Blythe, D. and John, N.W.; 1998. Advanced Graphics Behind Medical Virtual Reality: Evolution of Algorithms, Hardware and Software Interfaces. In Proceedings of the IEEE Vol. 86 No.3.

[2] Negrea M., Pop C.O., Lungeanu D. 1998. 3D Visualisation in Dentistry. MEDINF'98. 165-171. 'Vasile Goldis' University Press. Arad.

[3] Hampson, E.L. 3rd eds. 1973 *Textbook of Operative Dentistry*. London : Heinemann.

[4] Faisal Mohamed, N.F., Chen, C.J., and Shiratuddin, M.F. 2001. An Interactive 3-Dimensional Web-Based Learning Tool: Simulating the Withdrawal Reflex Arc Concept. International Seminar on Learning and Motivation 2001 (ISLM 2001), 555-562. Penang, Malaysia. Pearson Education Malaysia, Sdn.Bhd.

[5] Nuha H. El-Khalili, Ken W. Brodlie, Distributed VR Training System for Endovascular Procedures", Proceedings of the fourth UK VRSIG Conference, ed. Richard Bowden, November 1st, Brunel University. (1997) 110-119.

[6] Pegden,C.; Shannon, R.; and Sadowski, R. 1995. *Introduction to Simulation Using SIMAN*. New York. McGraw-Hill, Inc.

[7] Riva, G. 1997. The virtual environment for body image modification (VEBIM): Development and preliminary evaluation. *Presence*, vol.6, pp.106-117.

[8] Tsoi, K.N. and Gröller, E. 8 April 2002 URL: http://citeseer.nj.nec.com/379785.html

[9] Mroz, L., Löffelmann, H., and Gröller, E. 8 April 2002. Citing Internet sources URL http://citeseer.nj.nec.com/mroz98bringing.html

[10] El-Khalili, N.; Brodlie, K.W and Kessel, D. 2000. WebSTer: A Web-based Surgical Training System, Medicine Meets Virtual Reality 2000, Ios Press:69-75.

[11] Nuha H. El-Khalili, Ken W. Brodlie, Architectural Design Issues for Web-Based Virtual Reality Training Systems", Proceedings of the 1998 International Conference on Web-Based Modeling & Simulation, ed.Paul Fishwick, David Hill and Roger Smith, January 11-14, San Diego, California. (1998) 153-158.