Bringing 3D to Teleradiology

Nigel W. John, Mark Riding, Ari Sadarjoen
Manchester Visualization Centre, University of Manchester
Manchester, United Kingdom

Liad Blumrozen
BioMediCom Ltd., Jerusalem, Israel

Abstract

The NOVICE project (Network-Oriented Visualization in a Clinical Environment) is developing a system for medical image data analysis and visualization through the web with the intention of demonstrating the effectiveness of such a system in a clinical environment. One element being addressed by NOVICE is the provision of teleradiology tools. This paper describes how three-dimensional models can be included in a teleradiology application by utilising the Virtual Reality Modelling Language (VRML) and multi-user extensions, including annotation tools. The result is the world's first web-based system for 3D teleradiology! We will present a detailed overview of the implementation and operation of this system, and indicate results from early use.

Keywords: Teleradiology, VRML, Multi-user, 3D, Medical.

1 Introduction

Teleradiology is the electronic transmission of radiological images and reports from one location to another. It is usual to include collaboration tools to allow the radiologist to discuss a patient's case with colleagues remotely. Teleradiology (and telemedicine systems covering other clinical areas) have been in use for well over ten years and there are several commercial solutions available. A large number of projects to develop and enhance such systems have been funded in Europe [1], and elsewhere. The radiological images transmitted will be 2D images (from CT or MRI scanners), or in some cases video streams (such as 2D ultrasound data). Very few solutions exist today that allow 3D data to be used in telemedicine. One example, however, is the TeleInViVo workstation [2], that facilitates the transmission of volumetric models created from 3D ultrasound data. It uses a custom message-passing protocol for data transmission and is currently limited to point to point transmission.

The NOVICE project (Network Orientated Visualization in a Clinical Environment) is developing a range of extensible Web-based visualization tools for medical applications that will work within a high-performance computing environment [3]. Access to compute resources is being provided through a simple web-based user interface using HTML, Java and other relevant technologies. The main objective is to provide the clinician with advanced functionality from an easily affordable desktop workstation. This will help to cut costs dramatically and make high quality medical image processing available without the large capital investment currently required. The project includes the provision of teleradiology tools using medical data obtained from a hospital scanner in the DICOM (Digital Imaging and Communications in Medicine) standard format [4] and stored in the NOVICE database. The provision within NOVICE of a JAVA based system for the transmission and annotation of 2D images has addressed traditional teleradiology. The Manchester Visualisation Centre (MVC) has developed this software. MVC has also been working with another partner in the project - BioMediCom Ltd - to investigate and produce tools for using 3D models derived from the radiological data within a teleradiology session. The development of this 3D web-enabled teleradiology system is described in this paper.

2 Background

The Virtual Reality Modelling Language (VRML) [5] is a platform independent, 3D scene description language, with support for interaction by the user, rather than just simple navigation through a virtual world. Although standalone applications exist to allow users to explore VRML worlds, VRML browsers are typically incorporated as a plug-in to an Internet browser, such as Microsoft's Internet Explorer or Netscape's Communicator. This allows VRML worlds to be published on the Internet in much the same way as an ordinary HTTP page. MVC and BioMediCom (formerly Silicon Graphics Biomedical) have been particularly interested in medical applications of VRML and have already demonstrated a wide variety of applications including volume rendering [6], and surgical training simulators [7], [8]. The World Wide Web (WWW) has proven to be an extremely cost effective environment for making such applications available to a wide audience and has great value in introducing the potential of 3D and virtual environments to clinicians.

Most of the VRML applications that we have developed to date have been single user applications. For a 3D Teleradiology application a multi-user VRML world is required i.e. a world that can be accessed by many remote users at the same time in such a way that any one user can interact with and see other users "logged into" that world. The current VRML specification does not include support for multi-user worlds but several solutions do exist to provide this functionality, and we propose adapting one of these solutions for our 3D Teleradiology system. An extensive review of all currently available multi-user VRML solutions can be found in [9], three of the most popular being Vnet [10], Contact/Community Server [11], and DeepMatrix [12]. In all cases, each user has an avatar to represent themselves in the world - a 3D object rendered in every other participant's VRML browser. When a user moves around the scene, his avatar moves with him. A chat mechanism is also provided that enables a user to type and send messages to other users currently logged in.

VNet was developed at the University of Waterloo in Canada. This product is in the public domain, and freely available. It uses Java to provide a client-server application, which takes care of all the multi-user functionality of a shared world, communicating any changes made to all users in the scene.

Blaxxun Interactive produce the Contact VRML browser and it has built in shared world capabilities, allowing a user to visit a multi-user world without needing to install any other software in addition to the browser. Although Contact is itself available for free, the Community Server product is required to create new multi-user worlds and this is a commercial product.

DeepMatrix is produced by Geometrek Inc. who are "an international collaboration between VRML experts, aiming to produce, and help others to produce innovative 3D Virtual Worlds on the Internet". Like VNet, DeepMatrix is developed in Java, and provides a client-server application that sits above the VRML browser, co-ordinating control. The product is open source and so freely available.

We have investigated the use of these three systems to determine their suitability in providing an appropriate environment for the development of a teleradiology system.

3 Methods

3.1 Evaluation of Multi-User Worlds

To identify a suitable multi-user environment for the development of our 3D teleradiology system, we looked at cost-effectiveness, ease of use, ease of development, platform independence, flexibility and stability.

Both VNet and DeepMatrix are client-server Java applications running above a standard VRML browser and provide multi-user synchronisation between each user's world. When a user navigates around his local copy of the scene, the Java client communicates the avatar position to the Java server, which in turn communicates this position to the Java client of all other users that are logged into the scene. The local copy of every user's scene is then updated with the new information, allowing all users' movement to be reflected in all other users' worlds. Java offers the advantage of platform independence and we operated both products successfully on Windows PCs and SGI IRIX workstations.

Contact does not use Java, and does not require any extra software to run multi-user worlds – all of the necessary support is built into the browser. The browser is only available for Windows, however, and the commercial Community Server product must be purchased if you want to develop new multi-user world.

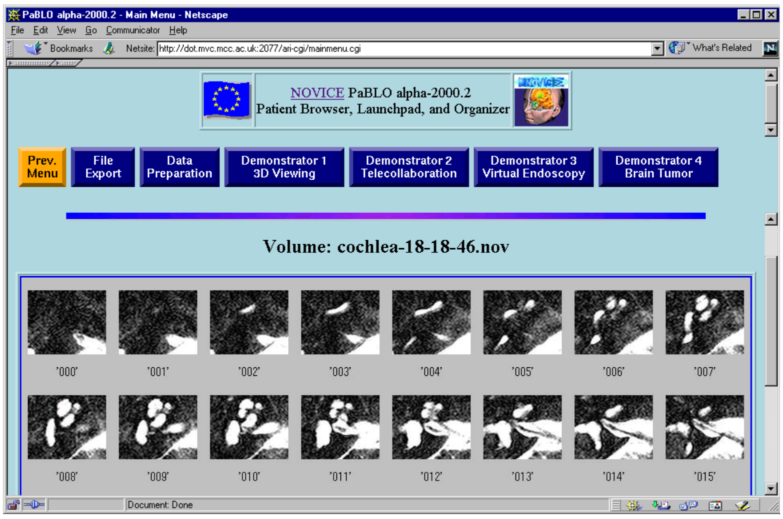
VNet facilitates synchronisation of user avatars between scenes, but this is as far as VNet goes with collaboration. There is no provision for allowing multiple users in a scene to collaborate and interact with other objects. In essence, VNet can be thought of as using VRML as a 3D front-end to a chat applet, with little support for complicated scenes that require distributed interaction. Deep Matrix has a big advantage over VNet in that it does facilitate multi-user scenes to be built where all the users can interact with not only each other, but also the scene itself.

Stability of these multi-user environments is a problem and certain Web Browser/VRML plug-in combinations work better than others. This is particularly the case for he Java based solutions. Further, a problem with all of the systems evaluated is that they do not provide a mechanism for ensuring that if an object in the scene can be manipulated, then only one user can have control at any one time.

Because it is freely available, it runs on different platforms, and it has support for interacting with objects in the VRML scene, we selected DeepMatrix as the basis for our 3D Teleradiology application.

3.2 Generating the VRML Models

Within the NOVICE project, medical data and software provided by the various partners is accessed through a single web-based user interface, called the Patient Lister, Browser and Organizer (PaBLO). A demonstration version of PaBLO is available on the WWW [13].


PaBLO alpha-2000.2 - Main Menu - Netscape

Netsite: http://dot.mvc.mcc.ac.uk:2077/ari-cgi/mainmenu.cgi

NOVICE PaBLO alpha-2000.2
Patient Browser, Launchpad, and Organizer

Volume: cochlea-18-18-46.nov

Document: Done
File Edit View Go Communicator Help
Bookmarks
What's Related
Prev. Menu
File Export
Data Preparation
Demonstrator 1 3D Viewing
Demonstrator 2 Telecollaboration
Demonstrator 3 Virtual Endoscopy
Demonstrator 4 Brain Tumor
'000'
'001'
'002'
'003'
'004'
'005'
'006'
'007'
'008'
'009'
'010'
'011'
'012'
'013'
'014'
'015'

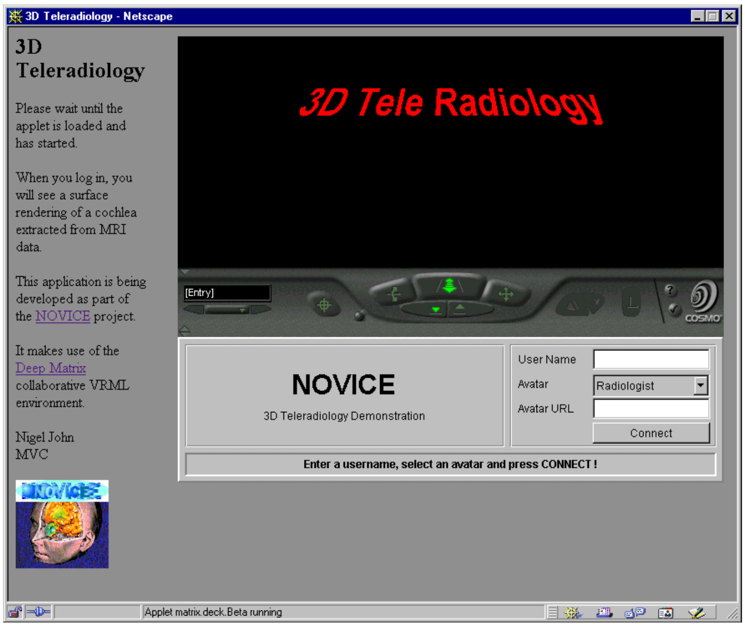
Figure 1: PaBLO Screenshot showing MRI Data of a Cochlea

One of the visualisation options selectable from PaBLO is to view an isosuface extracted from the medical data as a VRML file. AVS/Express software [14] running on an SGI Origin 2000 compute server is used to generate the isosurface – this software provides an implementation of the Marching Cubes algorithm [15] and will also convert the output into VRML. Polygon reduction techniques are applied to the resulting isosurface to ensure that the data size is minimised for efficient transmission over the WWW. The input data set is the patient's radiological images selected from the NOVICE database; the viewing parameters are entered through a web form in the PaBLO browser. Once generated, the clinician can examine the VRML isosurface in his Web Browser. If desired, he can also initiate a 3D Teleradiology session so that other users can then log into a world containing this object – see below.

3.3 Integrating PaBLO with the Multi-user VRML Environment

When the clinician initiates a 3D Teleradiology session, a script is run which will start the DeepMatrix server applet on the Origin 2000. The server applet is configured to make a VRML client world containing the 3D isosurface object available for collaboration. The client world must conform to the template required by the DeepMatrix software [16] and include custom **`PROTO`** nodes and **`ROUTE`** statements that deal with events which are to be distributed to other instances of the same world. The data to be viewed in the shared world – in this case our isosurface object – must be contained within the first **`Group`** node defined in the client world. We have written a program (in C) to create this VRML file at run-time, with the path (or URL) of the appropriate medical object passed as a command line argument. It is included in the VRML client world using an **`Inline`** node. In this way, every time we want to view a new 3D object, a new teleradiology session is initiated, linked to the appropriate file.

PaBLO provides an option for other users to join an already initiated 3D Teleradiology session. If selected, the user is presented with a login screen as depicted in Figure 2.



3D Teleradiology

Please wait until the applet is loaded and has started.

When you log in, you will see a surface rendering of a cochlea extracted from MRI data.

This application is being developed as part of the NOVICE project.

It makes use of the Deep Matrix collaborative VRML environment.

Nigel John
MVC

NOVICE

3D Teleradiology Demonstration

User Name:
Avatar: Radiologist
Avatar URL:

Enter a username, select an avatar and press CONNECT !

Applet matrix.deck.Beta running

Figure 2: 3D Teleradiology Login Screen

He can enter his user name, and then join other users in the collaborative session looking at the 3D isosurface model – see Figure 4.

3.4 The Viewing Tool

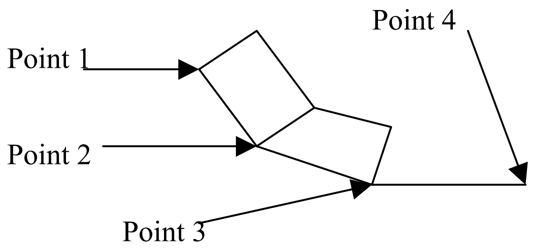
When participating in the Teleradiology session, we want all users see the 3D isosurface object from the same position to ensure that they are discussing the same view. A mechanism is then required to enable the 3D object to be rotated and examined as desired. Note that there can be a problem if all the users are in the same position as the avatars of the other users may block the view from that point. However, since there is no real need for avatars in a teleradiology application – the 3D isosurface object is the primary focus - the avatars can be disabled and removed from the rendering process altogether.

Grouping it with a **SphereSensor** node enables rotation of the 3D object. The user can then click on the 3D object and drag it around to a new orientation with the mouse. DeepMatrix allows this interaction to be mirrored to all users participating in the world. It achieves this by using VRML's External Authoring Interface (EAI) [17] and special 'Network' nodes inserted into the VRML scene, allowing events to be sent across a network. These nodes have no effect on the way the scene is rendered. This is an extremely flexible mechanism allowing even the most complicated single user VRML world to be converted to a multi-user world with the minimum of effort.

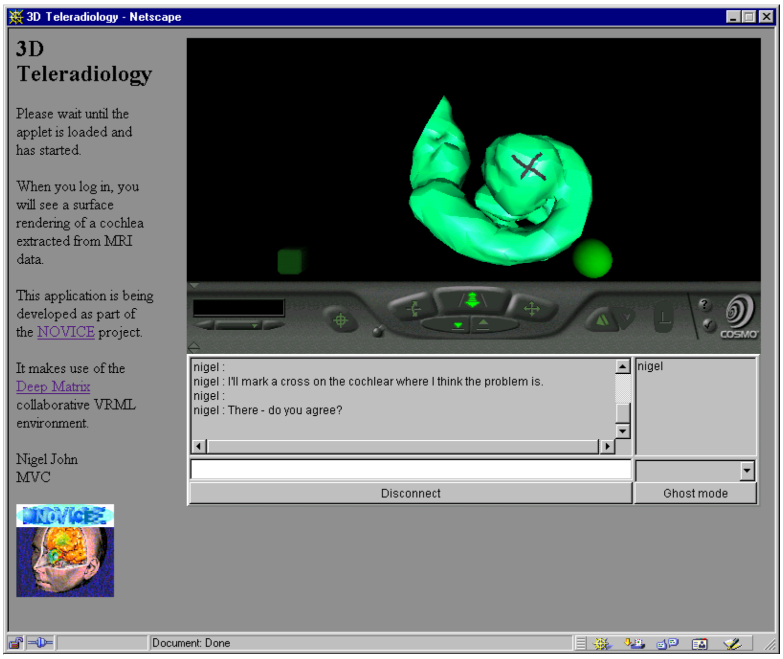
3.5 The Annotation Tool

An annotation tool has also been developed to provide the ability to draw or mark out regions of interest on the 3D isosurface object currently being viewed in the collaborative environment. This action is analogous to drawing on a canvas in an ordinary two-dimensional art package.

A **touchSensor** is also grouped with the isosurface model. When active, every time the user moves the mouse to a new position whilst the mouse button is depressed, and the cursor is over the isosurface model, an event is generated. At every event, information on the position on the object's surface that the cursor is over, the normal vector at this point, and the time the user clicked on the object can be obtained. This information is used to dynamically create the annotation marking on the object's surface by "joining the dots". A line can be drawn between each of these points using an **IndexedLineSet** node (which allows a list of co-ordinates to be specified, and the order in which to join them up). The drawback with this approach is that there is no control over the thickness of the line drawn. In CosmoPlayer, an **IndexedLineSet** line is a fixed thickness, no matter how far away it appears from the user. In effect, this means that a line drawn on the surface of an object up close, will appear to grow thicker as the viewer moves away from the object in the scene. This is not a desirable feature. An alternative is to use the **IndexedFaceSet** node to represent the line with a polygon strip of controllable thickness. This requires at least three co-ordinates to be specified every time a new "polygon line" is added to the annotation. However, only one new co-ordinate is provided by the **touchSensor**, and so a script must be written to calculate the others. If we add quadrilateral polygons, calculating just one extra point for each new point generated by the **touchSensor** – see Figure 3 – is enough to specify the polygon line. This new point should lie a fixed distance from the original point, to give the polygon line a pre-determined thickness, and should be positioned perpendicular to the direction of movement, to ensure that this thickness remains constant. The extra point can be calculated using the surface normal vector generated by the **touchSensor**, and the vector specified by both the point just generated and the previous point. The cross product of these two vectors is close to being parallel to the surface of the object, and perpendicular to the direction of drawing. The required coordinate is obtained by moving along the cross product vector a predetermined distance. This coordinate, together with the previous point used in the calculation and its perpendicular point, is then used to draw the polygon line. Note that the first quadrilateral is a special case as there is no previous data at this point.



As polygons are being created on the surface of an object, then a further problem is encountered due to depth aliasing - two objects are occupying the same space. To resolve this problem, the annotation is drawn so that it does not lie exactly on the surface of the medical data, but just above it. We make use of the surface normal associated with each point to calculate a position just above the surface of the original object. Moving along this vector a small amount from each point in the polygon line allows it to be raised by the required amount. This technique is effective for all faces of complex objects positioned anywhere in the scene.



3D Teleradiology

Please wait until the applet is loaded and has started.

When you log in, you will see a surface rendering of a cochlea extracted from MRI data.

This application is being developed as part of the NOVICE project.

It makes use of the Deep Matrix collaborative VRML environment.

Nigel John
MVC

```
nigel :
nigel : I'll mark a cross on the cochlear where I think the problem is.
nigel :
nigel : There - do you agree?
```

nigel

The line annotation is shared between the worlds of all participating users, by sending the co-ordinates and co-ordinate index of the object across a network node, just as with the rotation field described above. See the snapshot in Figure 4 for an example.

3.6 Solving the Contention Problem

The interaction tools described above are needed if the teleradiology system is to be of any practical use. It is important that only one user at a time can access these tools, however, otherwise the behaviour of the system is undetermined. DeepMatrix and the other multi-user worlds that we investigated have not addressed this contention problem.

To solve the contention problem a switch mechanism has been included in the VRML scene to determine which user is in control. A VRML "button" object has been added to the client world (the sphere object in Figure 4) grouped with a `touchSensor`. To take control of the world, the user clicks on the button and an internal javascript then enables the viewing or annotation tool for that user's instance of the client world only. If another user then tries to take control, they are granted it and the current controlling user has his control revoked. This is a simple solution but has proved adequate for our 3D Teleradiology application.

A further toggle switch has been included in the client world to allow the user who is in control of the world to switch between using the viewing tool and the annotation tool.

4 Results

We have created an effective application for 3D Teleradiology using standard Web-based technologies. This paper has focussed on the technical issues involved in implementing such an application and described the tools developed to enable collaboration between several users. A novel method for 3D annotation in VRML has been presented, and a method to avoid contention problems has been discussed.

Stability of the DeepMatrix (and similar) software is an issue. A solid interface between the Web Browser and the VRML plug-in is vital, and this is not always the case. For example, the combination of Netscape

Communicator and CosmoPlayer crashes if the browser window is closed whilst the user is still connected to the DeepMatrix server. This is due to a bug in the Netscape software. These problems are being addressed by the latest releases of browser and plug-in software, however, and will eventually disappear.

We have used the system successfully with up to four users. The system can cope with many more users than this number, but there is rarely a need to support more clients than this in a typical teleradiology application.

5 Conclusions and Future Work

The first version of this system is currently available to the clinical partners in the NOVICE project. Comments on the tool have been favourable with the sole reservation that the clinical usefulness of such a tool is unproven since similar tools have been available before. Established clinical data is required to assess the usefulness of this type of tool. The clinical end users in NOVICE are therefore being consulted and appropriate data identified for this purpose. The cochlear data used as an example in Figure 1 and Figure 4 provides one example of data where 3D does provide significant added value [18], and would be appropriate for a teleradiology session. Other examples will be readily identified as this type of tool becomes more widespread, such as the sharing of 3D ultrasound volumes as supported by the TeleInViVo system.

Additional annotation tools are also planned. We have already created a text annotation tool that can be integrated with a standalone VRML world. Work is in progress to provide this capability in the multi-user environment described in this paper.

The use of web-based technology has provided an extremely flexible and cost-effective environment for the provision of our 3D Teleradiology application. We are confident that web-based tools such as these will become common place in a clinical environment.

Acknowledgements

The NOVICE project (Network Orientated Visualization in a Clinical Environment) is a collaboration between AVS A/S, BioMediCom Ltd., Sistemas Expertos SA, Rasna Imaging Systems Srl, Foster Findlay Associates Ltd, University of Manchester, Central Manchester Healthcare Trust, Hospital San Juan de Dios, Clinica Femenia and University of Pisa. The project is funded by the European Community under the ESPRIT project EP26342.

References

1. Beolchi L (Editor), European Telemedicine Glossary, DG XIII-B1: Applications relating to Health, ISBN 92-828-7147-9, 1999
2. The TeleInViVo Project Web Pages, http://www.igd.fhg.de/igd-a7/projects/teleinvivo/teleinvivo.html
3. The NOVICE Project Web Pages http://www.man.ac.uk/MVC/projects/NOVICE/
4. Best D, Understanding DICOM 3.0, Kodak catalogue number 4B8915
5. The Virtual Reality Modeling Language. International Standard ISO/IEC 14772-1:1997. http://www.web3d.org/technicalinfo/specifications/vrml97/index.htm
6. Hendin, O, John NW, Shochet O, Medical Volume Rendering on the WWW using JAVA and VRML, Proceedings of Medicine Meets Virtual Reality (MMVR): 6, San Diego, pp34-40, January 1998
7. John NW, Phillips N, Surgical Simulators Using the WWW, Proceedings of Medicine Meets Virtual Reality (MMVR) 2000, Newport Beach, California, January 2000.
8. Phillips N, John NW, Web based surgical simulator for Ventricular Catheterisation, Journal of Neurosurgery, April 2000
9. Roehl B, Shared Worlds Review, VR News, ISSN 1360-3485, Vol. 8 Issue 6, July 1999
10. VNet 1.1b1. http://ariadne.iz.net/~jeffs/vnet/

11. Blaxxun Interactive, Community Server 4.0, http://www.blaxxun.com/products/server/index.html
12. Reitmayr G, Carroll S, Reitemeyer A, et al. DeepMatrix – An Open Technology Based Virtual Environment System. The Visual Computer Journal, October 1998
13. NOVICE PaBLO alpha-2000.1 Patient Browser, Launchpad, and Organizer, http://dot.mvc.mcc.ac.uk:2077/ari-cgi/pablo.cgi
14. Advanced Visual Systems Inc., AVS/Express, http://www.avs.com/products/expovr.htm
15. Lorenson WE, Cline HE, Marching Cubes: A High Resolution 3D Surface Construction Algorithm, Computer Graphics, Vol. 21, No. 4, July 1987
16. DeepMatrix Ducumentation, http://www.geometrek.com/developer/matrixdoc.html
17. External Authoring Interface, http://www.web3d.org/WorkingGroups/vrml-eai/
18. Adams WM, Laitt RD, Gillespie JE, Ivers C, Hartley, C, Ramsden RT, Jackson A. MRI assists plannng in cochlear implant. Diagnostic Imaging, 1998, 14, 29-35.