WebSTer: A Web-based Surgical Training System

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Abstract. Training of medical staff on minimally invasive surgery (MIS) is an area where new effective training methods are needed. We have studied stent grafting, a type of MIS, which is used to treat abdominal aortic aneurysm. Our analysis revealed that this procedure requires a range of motor, perceptual and cognitive skills. In this paper, we present a training environment that could be used to acquire these skills. Our proposed solution differs from the usual VR solutions by operating within the World Wide Web as an environment for our system. This paper discusses how our solution covers the training skills and presents the results of an appraisal process, which we conducted to evaluate our solution.

1. Introduction:

Since the early 1990's extensive attention has been paid to training surgical staff inminimally invasive surgery (MIS). Because of the special features of this type of surgery, it requires the development of new skills . Dumay and Jense highlighted these distinctions and discussed requirements and technical issues associated with this problem [1]. A number of solutions to this problem have been proposed which either focus on a specific MIS application or provide a generic solution- e.g. [2,3].

Utilising Virtual Reality (VR) technology is a shared feature of these solutions. The reason for this is obvious; VR offers a realistic environment and natural methods of interacting with it. Despite the huge efforts made to apply VR to MIS there are few clinically useful applications. Limitations of VR technology have kept surgical training solutions trapped in research laboratories. At the same time, we witness globalisation of software and information because of the World Wide Web (WWW). The emergence of *web-based applications* means that a solution to a particular problem can be shared and utilised by any user with Internet access. Thus, at the School of Computer Studies, University of Leeds and in cooperation with St. James' University Hospital, we investigated the feasibility of providing a web-based surgical training system as a solution to staff training.

This paper reports results of this project. First, we present the hypothesis behind this work- section 2- and the application area, which motivated it- section 3. Section 4 presents our solution and discusses the surgical skills covered by the system. Section 5 reports the results of evaluating our solution by medical expertise. This section transfers knowledge that we learned from this work and raises possibilities for future research.

2. Hypothesis:

VR is attractive as a method of training in MIS. In theory surgeons could master new techniques in a virtual environment before operating on patients. A number of systems have been developed (see [4] for a review), but all suffer from a number of limitations. These are due to the complexity of the procedures as well as the special requirements of VR technology. This situation demands high specifications, which often require expensive solutions. In addition, the VR solutions require special dedicated platform dependent peripherals, which only provide limited collaboration - a small group within one physical location.

In contrast, the WWW offers accessibility and distributed computing which lends itself to more popular solutions and wider collaboration. Furthermore, low cost is another feature of web-based applications since the only requirements are a web browser and plugins. Refer to [5] for a definition, classification and examples of web-based applications.

We hypothesise that providing a VR surgical training system on the web will provide an affordable and accessible solution. This solution will have to be platform independent and scalable- solving some of the deficiencies of VR solutions. These features are gained at the expense of the degree of complexity and realism that can be achieved. Hence comes the question: can we achieve enough realism to provide a useful surgical training system on the web?

3. Application:

Abdominal aortic aneurysm is an abnormal dilation of the abdominal part of the aorta, which is frequently fatal if ruptured. Conventional surgical repair requires a major operation. An alternative treatment strategy is endovascular stent grafting. This is a complex form of MIS performed by a team of radiologists and surgeons. We have investigated the previous hypothesis by developing a web-based surgical training system to train radiologists and surgeons in the necessary skill to perform endovascular repair of abdominal aortic aneurysm (AAA).

The goal of the procedure is to place a stent-graft within the aorta and thus reduce the pressure in the aneurysm sac.. The stent graft is a combination of a metal skeleton and a a polyester fabricgraft. The stent-graft is delivered inside a catheter and is positioned using x-ray guidance and interventional radiological techniques.. The successful completion of the procedure means that the aneurysm is excluded from the circulation, there is no leaking of blood to the aneurysm and the stent-graft does not block any vital branch arteries.

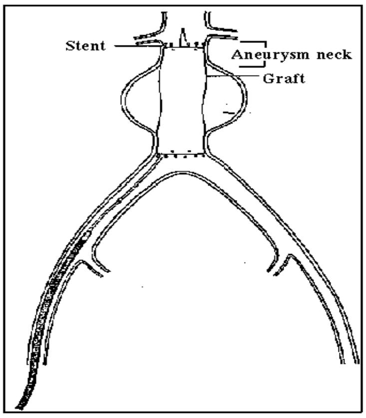

Figure (1) – Abdominal Aortic Aneurysm

For the procedure to succeed the graft must be correctly sized to achieve a seal against the vessel wall. Accurate assessment of the aneurysm size and morphology is necessary to select an appropriate stent graft. The distance from the renal artery to the aneurysm -known as the aneurysm neck, refer to Figure (1)- should be greater than 1 cm. The distance from the bifurcation to the distal end of the aneurysm as well as the diameter and length of the aorta are important pieces of information to determine the required size and length of the stent-graft.

The femoral arteries are exposed by surgical dissection. A guidewire and catheter are manipulated through the iliac arteries into the proximal aorta. The stent graft is introduced over the guidewire and angiography is performed to ensure accurate positioning. Angiographic images are taken again to check the position of the stent, and ensure that a seal has been achieved.

We have performed a task analysis on this procedure and classified the different tasks according to the cognitive skills required to perform each task. This analysis resulted in identifying two essential pieces of knowledge: an appreciation of the 3D arterial anatomy of the patient and the initial measurement performed. Furthermore, to manoeuvre the catheters and guidewires the operator must have a combination of eye/hand coordination and force perception. Based on these requirements we aimed to develop a training simulator which included the following features :

- Pictorial media to build the representational skill of anatomy modelling in 3D space.
- Tactile media which gives force feedback in response to user actions to build the force perception- psychomotor skill.
- Verbal instructions and practical environment to practise the procedural and automated tasks such as the measurement task.
- An environment with a wide range of anatomical models to practise the decision making process of positioning the stent.
- An interactive environment for the manipulation of surgical tools and getting the result of this manipulation such that the visual/ kinesthetic interaction is similar to the required eye/hand coordination in the real life situation.

In the next section, we will introduce WebSTer, our web-based surgical training environment to train radiologist trainees on Interventional Radiology procedures.

4.WebSTer:

The task analysis presented in the previous section identified that some skills necessary to perform the surgical procedure can be transferred via verbal instructions and demonstrations to introduce them to the trainee- e.g. procedural skills. Meanwhile, the representational and decision making skills require practice to acquire. Thus, our solution should support two main stages of training: the background stage is the stage where the trainee acts as a recipient of information; while the practical stage involves the trainee's interaction with a controlled training environment. The training environment has been developed in accordance with the server-client architecture of the web. It has been implemented with platform independent web technologies, such as VRML and Java. Refer to [5,6] for details of the components of this simulator and a technical description of its implementation. Figure (2) shows the virtual environment that the trainee receives at the client side.

In this section, we will focus on the functionality of our solution. We will discuss how we provided the list of requirements mentioned in the previous section.

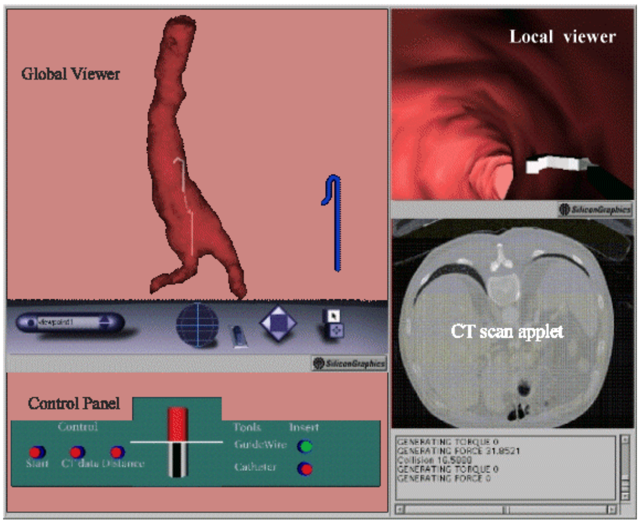

Figure (2) – WebSTer User Interface

4.1 Background training:

In order to support the early stages of training in our application, we have created some web pages to give instructions and demonstration information. The instructions web page includes description of the anatomy, surgical tools used and the steps of the procedure. Another page provides a set of movies, which were captured when we practised the manipulation of a guide wire and a catheter in a silicon mockup of the aorta. The goal of these videos is to demonstrate the procedure of manipulating the surgical tools as well as to give an idea of the difficulties expected. The web pages also provide links to other sources of information and instructions of how to use the simulator.

4.2 Representational skill:

Representational skill refers to an appreciation of the process or object, which improves the performance of the task. In our application it is necessary to train new radiologists to visualize the 3D structure of the arteries from the sequence of 2D CT slices taken pre-operatively. The traditional method of doing this is to view the slices consecutively. WebSTer provides this traditional viewing method alongside an interactive CT slice display in the simulator. Thus, a Java applet "CT scan applet"- see Figure (2)- is used to display the slices that were used to construct the 3D geometry. The selector widget provided in the global viewer- see Figure (3)- links between a position on the 3D model of the blood vessel and the current displayed slice. For experienced radiologists, this tool would act as a link between the traditional method of viewing anatomy as slices and the 3D representation provided. On the other hand, for a trainee, this tool would help to establish the representational skill.

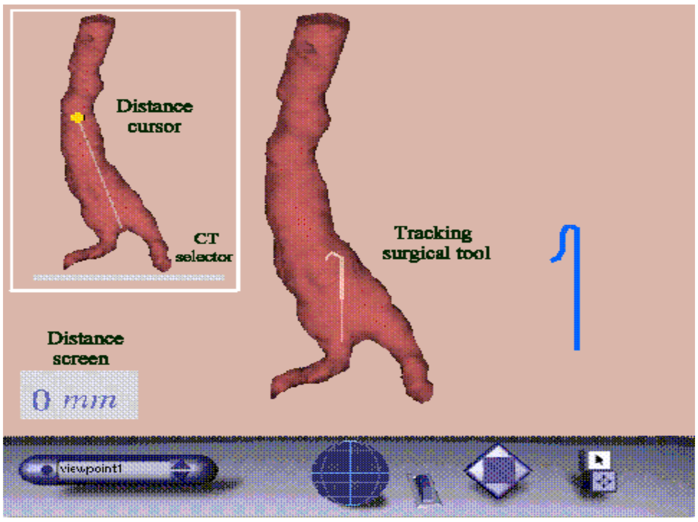

Figure (3) Global viewer

4.3 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.. The verbal instructions are supported by the web pages in the background training mentioned earlier. Meanwhile, WebSTer provides an example of procedural support in the simulator by including a measurement tool in the global viewer- see Figure (3). This tool can be used by the trainee to measure the aneurysm neck, bifurcation distance and diameter of the vessel, which are essential to decide the suitability of the procedure and to plan it. A cursor attached to a plane sensor is provided to sweep the surface of the aorta highlighting the area covered. The distance covered in the direction of motion is then reported on a text screen panel at the bottom left corner of the global viewer.

4.4 Decision making skill:

In order to support the decision making skill, we provide a procedure evaluation form. The trainee is asked to perform the required measurements using the tool described in the previous section. Based on these measurements the trainee decides whether this case is suitable for an endovascular procedure and adds comments about expected difficulties and tools used during the procedure. The contents of the form can then be kept in a file to evaluate the trainee. A number of CT scan data sets of patients with AAA have been obtained from St. James's University Hospital. 3D geometry is extracted from the data sets and is made available for trainees to choose from- providing the variation necessary to build such a skill.

4.5 Manipulation of the surgical tools:

The simulator provides an environment where the trainee can practise the manipulation of surgical tools inside the arteries, which will partially support the eye/hand coordination skill. The simulator models two surgical tools- a guide wire and a catheter. The geometric representation of the tool models the tip of the tool as a 3D model with a square cross section. Meanwhile, the behavioural model of the tool- e.g. bending and twisting- is modelled using a physically-based model which resides on the server side- refer to [6] for details of the physically-based technique implemented. The trainee manipulates the models in the same way that a surgical tool is manipulated in real life- i.e. push/pull or twist clock/counter clock wise along its axis.

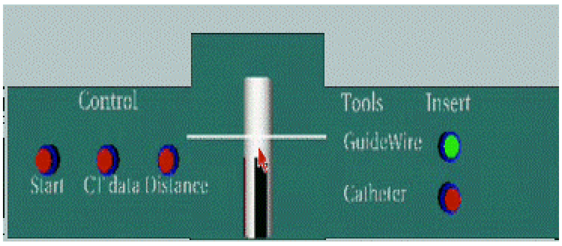

Figure (4) – Control Panel

Figure (5) Local viewer

The simulator provides a virtual scope- a cylinder which appears in the middle of the control panel, see Figure (4)- to allow these interactions. Using this virtual tool the 2D motion of the mouse device can be interpreted according to the need of our application. Vertical motion applied to the virtual scope is interpreted as pushing or pulling forces. Meanwhile, the horizontal motion is interpreted as rotation clockwise or anticlockwise. These manipulations are translated into force values and rotation angles and are sent to the simulation engine- on the server side- to compute the tool behaviour. The result of these calculations is sent back to the client side and is translated into two changes in the user interface. First a change in the surgical tool position and shape in the global viewer- see Figure (3). The global viewer shows an external view of the vessel structure and the surgical tools. This serves as a pursuit tracking mechanism to assist the trainee in knowing where they are and where the target is. In addition, this viewer tracks the route traversed by the surgical tool using thin lines. Secondly, the new position of the surgical tool affects the view point of the local view- which serves as an internal (endoluminal) view- see figure (5).

4.6 Psychomotor skill:

Radiologists try to limit the x-ray exposure of the patient and the medical staff by minimising the number of angiographic runs and the fluoroscopy time. Thus, while inserting the guide wire, force felt at the end of the tool is the only guide to the radiologist. This requires a psychomotor skill which is defined as a skill where movement is based on kinesthetic cues. This skill can be transferred by a tactile media which translates situations like hitting a vessel wall into haptic feedback. In order to include such a feature in our training environment, we require special input/output devices. In our solution, we are not able to deliver more than the usual interaction peripherals- mouse and keyboard. This is due to the fact that no standard browser supports any other devices. Consequently, we substitute the force feedback by an alternative sensation- namely audio and visual- in order to provide a partial support to this skill. Our virtual scope- described in the previous section- represents the strength of the collision force between the surgical tool and the walls with the intensity of a red colour, which is reflected on the top part of the tool. In addition, the simulator will display a sound clip to alarm the trainee that a collision has occurred.

5. Evaluation:

Through the development of WebSTer we have faced a number of problems which identified limitations in the current web technology. For instance, VRML does not support collision between objects and does not consider the object physics. In addition, web technology lacks efficient and standard support for other I/O devices. Such limitations may eventually be corrected by new technologies. However, a more important lesson to learn from this experience is how useful is such an application for training. In order to answer this question, we conducted a subjective evaluation using a questionnaire, which included a rating scale. The audience of our appraisal test covers a wide range of medical expertise - radiologists, surgeons and medical visualization experts. The evaluation process consisted of two sheets: instruction sheet and evaluation sheet. The instruction sheet takes the participants through the features of the system and asks them to refer to the evaluation sheet at the end of each section to give a score and to add comments. In addition, the participants are asked to reflect on the potential of using such web-based application in the medical field, to name a single aspect that would greatly improve this work and to add any general comments. The following is a list of the results of this appraisal process:

- Verbal instructions and demonstration provided by the web pages are useful for training purposes. However, the level of the medical contents of these pages should be determined according to the audience- e.g. experienced radiologists or the public.
- The interactive display of the CT slices is a useful tool for non-radiologists and radiology trainees, as it gives the necessary link between the 3D model and the anatomical structures in the CT slices. Meanwhile, the consecutive slices display is thought to be more useful to experienced radiologists.
- The procedure evaluation form is thought to be a useful technique for assessing the trainee in such an application. It was suggested that the same technique can be used to assess other decision making skills involved in the procedure such as choosing the right catheter and guide wire for each case. Furthermore, the variety of models provided is thought to be good for enriching the trainee's experience.
- The visual feedback provided by the simulator is not achieving the desired aim. It has been suggested to use visual motion resistance as an alternative- where collision is represented as a slow down or complete stopping of the tool's motion.
- The complexity of the surgical tool behaviour requires computationally expensive models to simulate such behaviour. The simplified models which we adopted to ensure interaction are unrealistic. In addition, the rendering was lagging the user

interaction and caused confusion, which reduced the transfer of the training message. Consequently, it is felt that accurate simulation of reality is not essential for training purposes as much as conveying the training message. For example, it might be more useful for a trainee to receive an immediate error message or warning bleep when applying excessively big forces than to get the same information delayed after going through the mechanical calculations. The appraisal process seems to give the message that "realism is more important then accuracy". Two approaches have been suggested to achieve this target. One is to pre-calculate the possible scenarios of a case, then to use some sort of rule-based system to either select the next action based on the pre-calculated cases or interpolate it based on them. The second suggestion is to simplify the surgical tool model into segments of rigid objects and attempt a more client-based approach.

Suggestions for future enhancements were gathered through the appraisal process. These suggestions focus on providing specialised input/output devices for force feedback. Furthermore, it has been suggested that user applied forces, collision strength, number of trials attempted to achieve a task and errors performed during the training would be detected and stored in a trainee profile and then used later for more systematic evaluation of the trainee. Finally, a more formal evaluation for the skills that has been well presented in the system is needed to measure the transfer of these skills to real life. For example, using the interactive CT display with the 3D geometry was unanimously thought to be a useful tool by our evaluators. In order to answer the question "Does this tool build the representation skill of new radiologist?", two groups of radiology trainees would be involved in a formal evaluation process, whereby one group is trained using the conventional methods and the other using this tool.

6. Conclusion:

In this paper we have presented work that has been carried out to test the feasibility of providing a web-based surgical training system. We have attempted to tackle a reasonably complex problem and provided a good starting point to solve it. The evaluation process reported in this paper suggests that the presented system is useful in identifying difficulties involved in developing such an application.

Despite the limitations in the current technology, the web is able to support a prototype training application. The question that is still to resolve is the degree of realism versus accuracy that is required in web-based training applications.

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