The Design Considerations of a Virtual Reality Application for Heart Anatomy and Pathology Education

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Abstract. Anatomy and pathology of the human body are complex subjects that cannot be elucidated easily to the medical students through traditional description and illustration methods. The proposed interactive system aims to present clear information on demand. For enhancing further the three-dimensional understanding of the anatomical information, a virtual reality environment was developed in order to accommodate different 3D models of the human body. In this case we opted for the heart model as it presents a unique section of the body that can produce motion and sound. The produced model was further simplified for use by patients who wish to understand better the generic anatomy and typical pathologies of the heart. Additionally the paper presents the data results of the system evaluation performed by ten users. The derived results although promising, highlighted some benefits and drawbacks of the proposed system that we aim, to improve in the near future. Finally the paper concludes with a plan of future work which will entail further interactivity through audio incorporation and gesture recognition.

Keywords: Virtual Reality, HCI, 3D Visualization, Heart Disease, Anatomy, Pathology.

1 Introduction

The transfer of anatomical information and knowledge has been of great importance to medical practice for centuries. This has however been sidelined over the past decades and the decline was more predominant in medical schools where, changes to teaching methods, reduction in curricular teaching time and reduction in staff have led to limited teaching of anatomy. Concerns have been raised on the future of anatomical knowledge provided at an undergraduate level and unfortunately, these have been reinforced by reports of errors due to low levels of anatomical knowledge [1].

Initial dismissal of detailed human anatomy teaching was primarily attributed to problems with the educational methods employed in such teaching. The role of traditional methods such as didactic teaching and cadaveric dissection, in a modern

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medical curriculum has been contested. These methods are obsolete to the current teaching practices due to practical and ethical issues. Dissection, viewed by traditional medical educators as the most effective method of learning anatomy [2], is currently affected by major shortages of cadaveric material as well as a variety of ethical issues involved in the practice. Furthermore, didactic teaching is mainly teacher-centered, not interactive enough and thus unable to stimulate students interests and encourage active student participation in learning [13]. Some institutions have removed these teaching methods from their curricula and are thus seeking more innovative approaches to teaching and learning anatomy. The reason most commonly cited for the reform in practices is that methods were outdated and not in keeping with current student learning needs and demands. In seeking to contribute and develop an innovative product, a virtual reality system was designed to effectively present anatomical information to a variety of audiences.

This paper details the design approach, the method of evaluation and the initial results for a virtual learning environment developed to aid the learning of human anatomy. It also introduces the interface and explains the rationale behind the design, which placed emphasis on a simplified interface and incorporated multi-sensory interactions. The virtual system provides users with the interactive environment to explore the anatomy of the heart using photorealistic three dimensional (3D) representations. It offers real time visualization in an immersive stereoscopic environment, providing anatomical information in a novel manner. The heart was chosen as the initial anatomical model for the virtual reality (VR) system due to the high rate of mortality from cardiovascular disease, especially in Scotland where the study takes place [14]. This renders the anatomy and pathology of the heart a high priority theme of the medical curriculum. The system was designed to suit various users including patient who could visualize the possible effect on the heart of certain risky behavior and in the process prevent future detrimental activities being taken, thus aiding in reducing patient risk factors.

2 Virtual Reality and Anatomical Information

The present reality of medical education and representation of anatomical information makes it ripe for innovation. This necessitates the adoption of a new approach to presenting anatomical information. To this end we created a novel design of an anatomy tutoring application using present advances in technology to augment the effect of the application tool.

Computerized tools have become increasingly important in most institutions that teach anatomy and are widely believed to be the alternative medium of choice. These tools have the ability to result in interactive learning, which is preferred to traditional resources of plastic models, or 2D illustrations that abound in most practitioners' workplaces. This has resulted in the creation of various interactive learning resources [11]. Different computerized tools have been developed, implementing various forms of technology including virtual, augmented and mixed reality. Currently augmented reality is becoming increasingly used in medical in-situ visualization [3]. Sakellariou et al implemented an augmented reality environment for training medics on the complex anatomy of the inguinal canal and had positive feedback in terms of knowledge enhancement and learning experience [4]. Results show that 3D virtual reality has the potential to reduce the learning curve [7]. In assessing the effect of a virtual reality environment, most studies showed the importance of a simplified interface and concluded that future works should include more intuitive interaction [3,4]. Also, these tools achieve increased active student participation in the learning process.

3 System Interface Design

To achieve the set objectives of enhancing knowledge and the learning experience the interface was simplified, as findings from previous research show the importance of a simplified interface [11]. Furthermore the design decisions were made based on their ability to reduce cognitive load and improve knowledge. This theory based design approach mainly relied on research from cognitive psychology.

The interaction was designed to offer the best anatomy learning experience, by providing real-time rotation and intelligent structural identification. This is a deviation from the limitations imposed by pseudo 3D, which is commonly used by most anatomy tutoring application, as pseudo 3D has been found to constrain the learners' ability go learn new anatomical information and impedes the exploration of structures [11]. The identification of individual anatomical structures, an integral part of the learning action, was simplified and made less cognitively stressful, by making it clearly visible. This was implemented with labels that were close to the structure being identified (Figure 1), in line with current understanding on the effect of proximity between images and

Fig. 1. Screenshot of the VR interface presenting a testing low-polygon heart model and the selection of the aorta

associating text [8]. To reduce cognitive load and augment knowledge storage, visual texts were also replaced with auditory cues. This reduced the burden of excess text, which as observed from previous trials disrupts the learning experience [11].

In creating the heart prototype, 3D models were developed by manipulating CT and MRI scan data with further enhancements utilizing 3D Max, a modeling software. This was aimed at increasing photorealism in the models whilst optimizing their polygon number to allow incorporation into Unity 3D gaming engine.

The use of a gaming engine offered unrestricted manipulation of models and liberates the application from limitations associated with pseudo 3D. Previous tutoring system utilized the pseudo 3D technology that entailed a combination of still images put together. Providing real time rotation and interaction improves the learning and enhances the exploration of individual structures.

The interactions, discussed above, were developed with Unity3D. The particular game engine was deemed ideal for such system as it offers great flexibility and compatibility with a vast number of other software packages and applications. To create the ideal immersive environment for the iterative development process, we utilised the Virtual Reality and Simulation Laboratory (VRS Lab) at Glasgow Caledonian University which offers large stereoscopic projection (3x2.5m) in combination with surround sound system and gesture recognition capacity.

Notably during the design and development the system was tested in the specific facility it was our intention to produce a final application that could perform equally well even with the use of a laptop. The latter hardware was able to reproduce the stereoscopic effect through the appropriate graphics card and monitor. Due to cost efficient requirements the system portability was one of the main objectives of the proposed system.

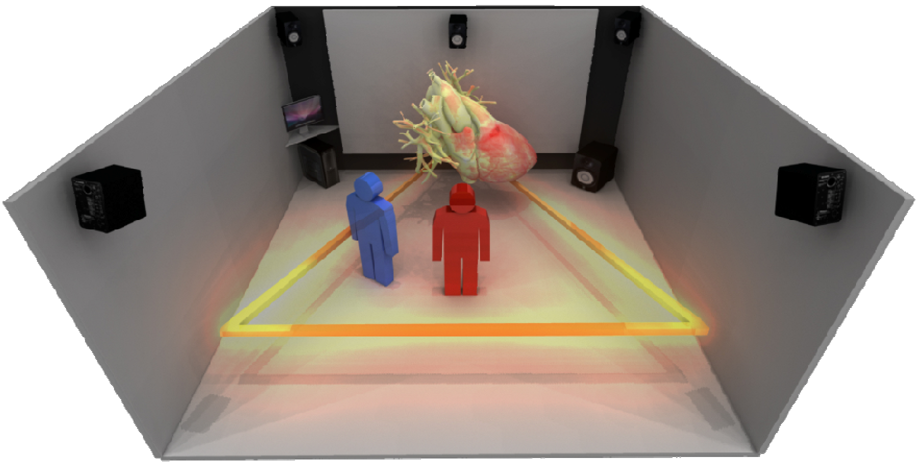

Fig. 2. Virtual Reality and Simulation Laboratory (VRS Lab) configuration which supports large scale stereoscopic projection and 3D surround sound system

4 Case Study Evaluation

This prototype application was designed primarily to suit the group of medical student users. Yet it was made clear that such as system could be utilised routinely for also enhancing patient information on related heart disease issues.

Although the learning requirement of these two groups differ, the application was designed so that depth of transferable anatomy knowledge could be adjusted; A detailed representation of the anatomy of the heart was presented to the medical students whilst a simplified version was presented to patients. Previous studies have shown that good anatomy grounding is beneficial to understanding pathology[11]. Patients' knowledge of anatomy is generally insufficient to fully comprehend the information provided to them by medical practitioners. This is further hindered by the inability of the average patient to reconstruct a mental map of verbally communicated anatomical terms and conditions by their medical practitioner. Studies have indicated that verbally presented information in the context of a medical consultation is neither well retained nor adequately comprehended by patients [15]. Real-time 3D medical visualisation offers a unique platform of communication between doctors and patients which could be employed easily in any computer or mobile device in a timely manner in order to aid information communication.

This creates a shift from traditional paper based material and aims to improve the ability of doctors and other health practitioners to convey simplified yet accurate anatomical information to patients. This could potentially help them make appropriate decisions, from life-style changes to coping with their diagnosis.

For the first stage of the evaluation of this application, a heart anatomical model was employed for an audience of lay public i.e patients. The heart model was initially used for evaluation as cardiovascular pathologies contribute to the highest mortality and morbidity statistics in Britain, and comparatively more in Scotland [14]. A photorealistic model of the heart was created from CT data. The developed model was accessed through a simple and clear interface which entail all the typical three-dimensional interactions such as rotation, zoom, pan and selection of individual sections. The latter are annotated in analogous fashion to medical anatomy books.

5 Results and Discussion

For the initial evaluation of the system we requested from ten users to test the system and provide us with feedback through a Likert scale (1 to 5) questionnaire and one to one interviews. The individuals chosen were members of the public with no specific medical background. Thus they had little prior knowledge on the anatomy of the heart. The questions presented to them after using the application are noted below:

1. The system helped me create a 3D mental map of the heart
2. I can remember most of the structures of the heart.
3. This learning experience was enjoyable.
4. The placement of labels helped me identify structures
5. I have a better understanding of the heart's anatomy

6. I can understand various cardiac pathologies after using this system.
7. Unrestricted rotation improved my learning experience
8. I can use this system on my own time without required support
9. Medical terminology was demystified
10. I would like to see similar applications for other vital organs

This preliminary evaluation offered succinct yet crucial information with regards to the system performance and acceptability from the users as presented in Figure 3. More analytically the system scored over 80% in all except one (question 6) of the questions. Question 6 scored 78% as some users felt that they can have a better understanding of particular pathologies than previously, although they were not sure of how much in-depth information they should acquire. Some of the users commented that even the simplified system presented some information probably more relevant to medical practitioners.

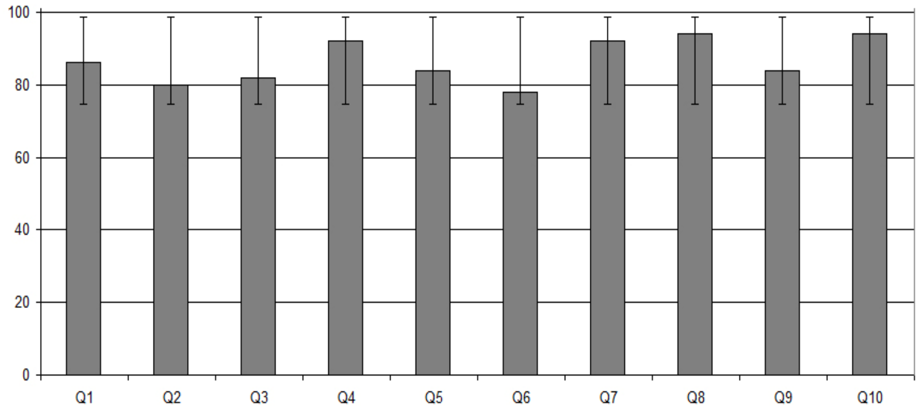

Fig. 3. Scores in percentage for each question derived from the 10 users

From a visualisation point of view the current 3D model of the heart was intentionally reduced to very low polygon count so as to optimise the system performance and test it in a typical laptop. The users noted that although the refresh rate of the stereoscopic visualisation was adequate, the 3D model requires additional smoothing of the surfaces and further optimisation.

The interface was considered user-friendly without any unconventional and unexpected manipulation tools. However we intent to improve significantly the system interactivity with the use of gesture recognition and audio tools. To this point, the users were in favour of annotations although a voice over description could further assist with the pronunciation of some complex terminologies.

Overall the system offered a good experience for the users and delivered to its promise to enhance the medical understanding of the users. Interestingly the users suggested that the particular system could be very useful for other organs and pathologies of the human body.

6 Conclusions

This work presented the design process of a prototype medical education system. For experimentation purposes we choose to develop a detailed 3D model of a heart. The proposed interface was developed with a view to support both medical students and patients. With this in mind the system offers a two fold approach which can facilitate both requirements with minor system alterations.

The first version of the system was evaluated by ten users and with the use of Likert questionnaire and post-trial user interviews. The preliminary results were promising and the subjective feedback highlighted some benefits but also drawbacks of the application that are planned for amendment in future versions.

For future work we plan to extend the visual information and blend it with 3D audio which will enhance the understanding of different heart diseases. We anticipate that the correlation of visuals and audio will offer a more realistic representation of heart pathologies and convey the subject matter in a clearer and more intuitive manner.

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