Virtual Reality Medical Training System for Anatomy Education

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***Abstract*— Medical education is a dynamic field that witnesses continuous evolution and development. The employment of Virtual Reality (VR) based visualization and training environments in the delivery of anatomy teaching transfers the learning experience from one that involves memorising the structures without a true understanding of the 3-Dimensional (3D) relations, to a process that involves a thorough understanding of the structure based on visualisation rather than memorising, which makes the learning process more efficient and enjoyable, and less time consuming. This paper describes the development of a Virtual Reality and 3D visualisation system for anatomy teaching. The developed system offers a real-time 3D representation of the heart in an interactive VR environment that provides self-directed learning and assessment tools through a variety of interfaces and functionalities. To ensure the accuracy and precision of the developed system it was evaluated by a group of medical professionals.**

Keywords - Medical Education; Virtual Reality; Anatomy; 3D; Heart.

I. Introduction

The field of medical education witnesses a constant process of evolution fuelled by the desire to develop teaching methods that are as realistic as possible in resembling the human body in all its complexity and variety. The aim is to provide future doctors with an educational system in which they can build a solid base of knowledge and skills to prepare them for interaction with true patients. As the live human body cannot directly be used to provide a teaching method for obvious ethical reasons, the quest continues to improve the teaching and learning experience, by developing teaching aids that offer a close likeness to the body, with its structures, functions and diseases, whilst doing so in an environment that does not compromise safety. Anatomy, in particular, focuses on the detailed structure of the different systems of the human body, and a variety of descriptive models to provide an in depth understanding have been used to facilitate this. There is, however, room for improvement and new methods that will enhance the current system by providing even better resemblance of the human body, in an attempt to achieve knowledge that will truly equip the student with the ability to interact with the live body later on.

There are several current and emerging technologies that have the potential to overcome the associated issues with the traditional teaching methods and enhance medical education. VR technology is one of these technologies that can improve education in many ways, [1]; most significantly, it can be used to train medical students to recognise and understand the structures or medical procedures, enables medical students to obtain knowledge and better understanding about the human body by interacting with it within a virtual environment, and can be used to manipulate medical data into the 3-Dimensional (3D) forms, [2-4]. Virtual Reality technology also enables the user to modify the relative sizes of the objects in the virtual environment and this practice is impossible to accomplish in reality. This is a significant point for the medical students as they can change the size (Zoom in/Zoom out) of the 3D model to gain better understanding and explore more details, [5].

To overcome the associated issues with the traditional medical teaching modalities a VR Medical System was developed to offer a contribution to the anatomy system process. Currently, the anatomy course consumes a considerable amount of the student's time, as studying requires a huge effort of memorising and repetition to achieve a solid grasp of the subject. The developed VR Medical System provides the student with long term, lasting knowledge of the anatomy of the heart.

II. Background

Through extensive review of existing teaching areas that require technological enhancement it was deemed ideal to engage with the medical disciplines as they involve direct and critical interaction with human beings, which requires a high level of knowledge and dexterities.

Historically, anatomy has been a backbone in medical education regardless of nation or specialty, [6-7]. Anatomy is involved in all medicine branches, in addition to the surgeon it is essential to anyone who: performs a procedure on a patient; carries out emergency procedures; examines radiological imaging; performs a physical examination of a patient; refers a patient to another doctor; or explains a procedure to a patient, [8]. Therefore, considering anatomy's importance in medicine an enhancement on the anatomy education modalities will add value to the medical education process.

The traditional modalities used in medical education are associated with numerous issues as they provide a limited spatial understanding obtained from didactic lectures and restricted anatomic dissection [9-11]. In addition, a spatial relationship understanding from traditional modalities (textbooks and 2-Dimensional (2D) images) is not clear; requires expertise to explicate, and lacks adequate detail to demonstrate a specific teaching point, [9]. Furthermore, the human cadaver which is one of the teaching anatomy methods is associated with several limitations, for instance, the rising costs, decreasing availability, and the decay in quality, [12-13]. These issues are overcome by 3D modelling which has enables visualization of the spatial relationships between structures from various viewpoints, is reusable, is of changeable size, and allows explorative details which improve understanding, [9].

To improve the realism of the simulation, VR is a perfect tool for the development of an interactive training system, [14-16]. For years, VR techniques have been utilised to supplement and in some cases substitute traditional medical teaching and training methods, e.g. simulators of surgical procedures, scientific visualisation, during-operation assistance, functional diagnostics, virtual endoscopy, and preoperative planning, [3, 17-20].

III. Materials and methods

The 3D heart model was developed using an Industry standard modelling application, a number of techniques and tools were applied. Although many other techniques exist for construction of 3D anatomical models, [21], a polygon based modelling technique was utilised for the construction of the complex geometry.

Polygonal models are "composed of a set of polygons, with accuracy and smoothness of the models governed by the number of polygons", [22]. Polygon modelling production methodology provides the developer with complete control over the construction of the geometry. This is vital as the proposed system is a real-time system, which requires a polygon budget in order to avoid any delay between the end user and the reaction of the systems functionality. The VR Anatomy System required dissection of various heart structures to reveal underlying geometry; multiple layers of geometry were constructed. The 3D models were built to allow certain interaction functionality, which included the freedom to manipulate and separate parts of the geometry. The polygon based modelling technique allowed the construction of separate and individual structures. Furthermore it provided the developer with more control over the look of the model enabling the creation of aesthetically pleasing models. Digital sculpting and photo manipulation techniques were utilised to achieve a photorealistic look. Normal mapping techniques were utilised to achieve a more detailed look on the low resolution models. This included digital painting, photo projection and hi-resolution detailing for normal and texture maps.

The model has been exported to Unity 3D [25] (a cross-platform game engine) to create the real-time Virtual Environment (VE). C# programming language was used to build the Real-time interface functions.

The development of the VR Anatomy System went through several phases and required close consultation with medical experts to ensure the highest level of accuracy and true representation of the human heart.

After gathering information from 2D images and anatomy textbooks as well as physical models, the system was designed. Contrary to the currently used traditional modalities the novel user interface provides a direct manipulation and interaction in a 3D space employed to navigate the heart model, which improves the student's internal 3D understanding and visualisation of the heart anatomy. Interactivity means that the user may pick and change objects in real-time, [19].

Furthermore, the interface includes real-time transparencies for specific heart structures to enable the students to comprehend the complex heart anatomy relationships.

Several sessions during which medical professionals reviewed the model at different stages of its development, led to the evolution of gradually more refined versions of the model, until the final design was agreed.

During these sessions the aim was to ensure true anatomical relations of the different parts of the heart. Special emphasis was placed upon the design of the conductive system of the heart (a group of specialised nodes and fibres that generate and conduct an electric impulse that causes the myocardium to contract), as the visualisation of the conductive system are not detailed on the cadaver.

There was also consultation with regard to the colour and texture of different parts and layers, attempting to achieve a realistic representation, whilst preserving the educational value of having different colours and shades for different structures. It was therefore decided to use different shades of flesh colours but with slight exaggeration to define various structures within the model. The labelling process of the heart structures was revised several times and some labels had to be altered to ensure precision and consistency. Finally, the position of the heart in the interface was set to the correct anatomical orientation.

IV. Results

The developed system provides valuable insights to both lecturers and students, by utilising emerging technologies to enhance training and teaching in the medical field. The system has the capacity to offer real-time and 3D representations of the heart structure in an interactive VR environment. This offers simulation capacity that has the potential to enhance the heart anatomy course. The heart model includes all the major anatomical structures of the heart. After generating the model, functionalities were added to enhance interaction with the model (dissect the heart into layers, rotate, enlarge and minimise the heart structures). Also, additional anatomical information is provided for each 3D structure.

To provide the system users with a complete teaching aid for general heart anatomy structure, the system contains 3 interfaces: main interface, anatomy interface and quiz interface. The main interface allows the viewer to switch between system screens (anatomy interface, quiz interface or exit system). The anatomy interface contains the real time 3D heart model which has all the provided tools to manipulate the 3D heart model, navigate the heart structures from different viewpoints, and show the anatomical information for each structure in the 3D heart model. Also to help the lecturer to evaluate students' gained knowledge for the anatomy of the heart, 25 questions were added in the quiz interface.

The system aims towards cost-effective, customisable, and accessible functionalities. The system is built once and the model is reusable in the same quality, whilst this feature is not obtained by using cadavers, physical models and 2D images. The Virtual Reality anatomy system is customised upon the viewer's preferred presentation, as the viewer can interact with the model by: enlarging, minimising, rotating, and dissecting layers, etc., whereas the physical model and 2D images limit the viewer with a specific view size, viewpoints and cut parts. Furthermore the accessibility of the VR Anatomy System is not adhered to predetermined hours in laboratories under supervision. As such it was deemed necessary to develop and embed the following features in the system:

- Helps with understanding the complex heart structure.
- Enhances the visualisation of the heart details.
- Eases navigating through the interfaces and options.
- Clarifies anatomical relations of the different parts by dissecting the heart into layers.
- Visualises cuts through the structures of the heart in several locations by opening different planes.
- Helps in gaining valuable knowledge by providing anatomical information for each structure of the heart.

A. *Features of the Heart Anatomy Model and System Interfaces*

1) Main interface: To introduce the viewer to the system screens and facilitate switching between pages, the main system's interface was linked to 2 interfaces; anatomy and quiz. The third icon is to allow the user to exit the system.

2) Anatomy interface: Using this part of the model, the student gains an in depth understanding of the structure of the heart, browsing through the anatomical structures by the process of dissection and manipulation to identify individual parts and their relations with others. In addition to visualising the heart in three dimensions, each structure is provided with a brief description of relevant anatomical information, which reinforces the learning experience. The design of the anatomy interface demonstrated in Fig. 1 aimed to provide the viewer with enhanced visualisation of the 3D heart structures in addition to "easy to use" functionalities. Therefore the interaction between the user and the VR heart model is made by selecting any of the provided functionalities in the tool bar (on the left of the screen: dissect structures (Move one), restart the process (Reset all), move all the shown structures (Move all), mark structures (Highlight), rotating the structures (Rotate all), enlarging the structures (Zoom in), minimising the structures (Zoom out), show, the ability to make the structures either visible or invisible (Show all, Hide all), identify heart structures using a probe (structure list), and exit to main screen (Exit)). As the height of the heart is more than the width, the toolbar is placed on the left hand side of the screen. This provides a virtual dissecting room providing the maximum amount of space in which the user can interact with the VR heart model (rotating, Zoom in, Zoom out, Moving, Hiding and resting structures) see Fig. 2 and Fig. 3. The system users are able to repeatedly dissect or reconstruct any area within the VR heart model. Some examples for the functionalities available to users contain:

- "Move one" to attract the user's attention to start moving an individual structure from the 3D heart model in the 3D space. Dissecting and inspecting heart structures is a primary tool to reveal hidden layers, interact with heart structures.
- Reset all: Whilst the user is navigating through the heart structure and moving structures (using 'Move One' tool), the user might lose the orientation of the heart view. Additional assistance is provided to help the user to go back to the original view. 'Reset All' resets the heart structures to their original positions and views.
- Move all: Moving all the structures of the 3D model at the same time in the space leaves more space to the user to focus on particular chosen structures in the screen.
- Highlight: By using this tool the user can highlight any structure in the heart model. Highlighting the structure gives the user information about the name of the selected structure and medical description.
- Rotate all: This tool offers the ability to view the spatial relationships between heart structures from numerous viewpoints. The student can approach the heart structure from different angles. This is in marked contrast to diagrams in textbooks as the viewpoint is fixed and cannot be rotated to reveal hidden details.
- Zoom in/out: The user is limited to view the heart in its real life size (cadavers, Physical Model), or to view the heart 2 or 3 times life. However, this system enriches the visualisation of the heart model by providing enlarging and minimising options.

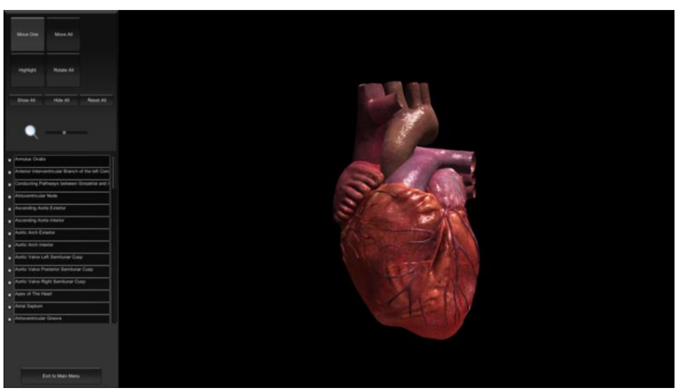

Fig. 1. The Anatomy interface in the VR heart anatomy system. Shows the wide space for interacting with the VR heart model, and the functionalities provided.

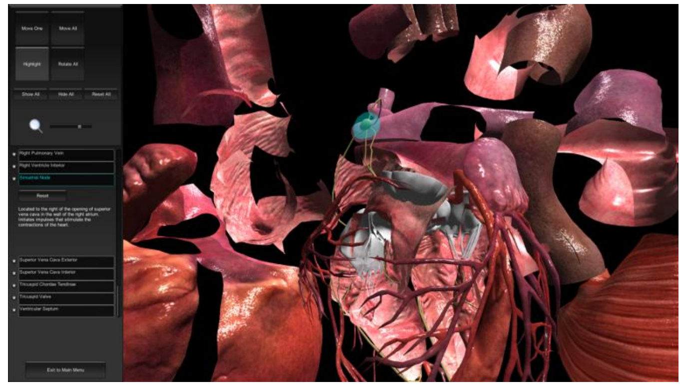

Fig. 2. Screenshot from the VR heart anatomy system shows the 'Move One' and 'Highlight' tool in use. The user dissected multiple structures from the VR heart model.

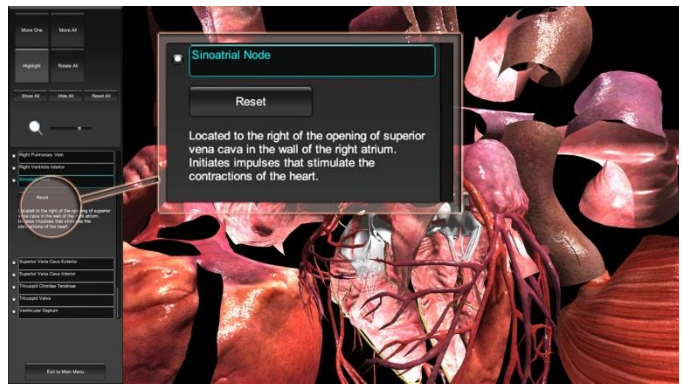

Fig. 3. Indicative screenshot shows the presented anatomical information for the selected label (Sinoatrial Node).

3) Quiz interface: The quiz interface is used as an assessment tool which could be utilised by:

a) The lecturer: in order to examine students by adding quizzes and exams. The lecturer can edit the quiz content and change the questions based on the examination aim.

b) The students: who could potentially use it for self-evaluation.

The quiz consists of 25 questions added to assess students' knowledge based on the functionalities provided in the anatomy interface. The entire questions were Multiple Choice Questions (MCQs). The student answers by selecting one of the multiple choices. In the quiz interface the user is able to navigate through the model and utilise the provided tools except the structures' list see Fig. 5.

The content of the questions focuses on assessing the ability to correctly identify anatomical parts of the heart, anatomical relations of different parts, and an overall understanding of the structure of this vital organ. The questions are suitable for exam purposes and can be used in that setting, aiding the examiner.

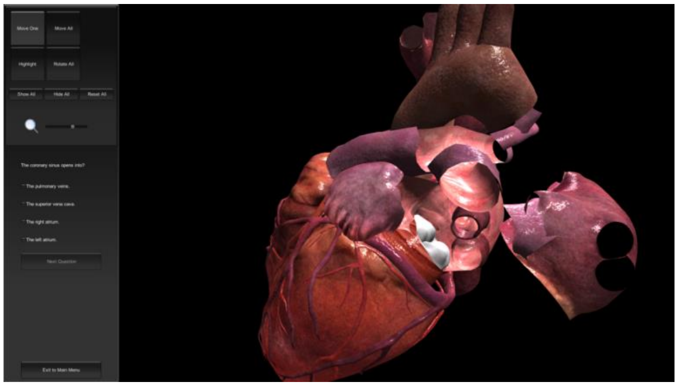

Fig. 4. Screenshot from the VR Heart Anatomy System, the user can strip away the various layers of the heart during the quiz without the labelling or any anatomical information

V. VIRTUAL REALITY ANATOMY SYSTEM VISUALISATION

Virtual Reality offers more realistic and "hands-on" learning experience, to develop the students' skills in a safe controlled environment, without the risks involved in direct interaction with the patient. Within a virtual environment the student will be able to gain a deeper understanding of the interrelationships of anatomical structures [23], and enjoy the learning and teaching while using the VR environment. Semi-immersive environment is delivered through:

- Remote manipulation of 3D data in VR laboratory: wireless and gesture recognition mouse, 3D projector and head tracker, 3D glasses and head tracker, projection wall, motion capture-tracking gesture recognition Fig. 5.
- Remote manipulation of 3D data in VR laboratory: wireless and gesture recognition mouse, 3D glasses and head tracker, 3D- Television (TV), motion capture-tracking gesture recognition see Fig. 6.
- Common mouse/keyboard on a stereoscopic display (PC with a powerful graphic card and active stereo 3D glasses) Fig. 7.
- To further enhance accessibility to the system, if the adequate tools for virtual environment are unavailable the user can still benefit from the system using a common mouse/keyboard on a flat computer screen.

Fig. 5. Remote manipulation of 3D data in semi-immersive environment (projection wall). This Figure shows the researcher using the system in the Virtual Reality laboratory using the projection wall and wearing active stereo 3D glasses (Glasgow Caledonian University/United Kingdom)

Fig. 6. Remote manipulation of 3D data in semi-immersive environment (3D TV). This Figure shows the researcher using the system in the Virtual Reality laboratory using the 3D TV and wearing active stereo 3D glasses (Glasgow Caledonian University/United Kingdom)

Fig. 7. Semi-immersive environment using common mouse/keyboard on a stereoscopic display. This Figure shows the VR Medical training System running using a powerful PC with a powerful graphic card and wearing active stereo 3D glasses to run the system. Virtual Reality laboratory (Glasgow Caledonian University/United Kingdom)

VI. INTERFACE AND VR MODEL OPTIMIZATION

After developing the VR Anatomy System, a group of 10 Medical professionals in United Kingdom (UK) were asked to carry out an evaluation of the system. They came from different medical backgrounds, such as surgeons, medical consultant and general practitioners.

In addition to the medical consultations throughout the design and development stages the precision of the medical aspects had to be evaluated after producing the alpha version of the system. Therefore, several aspects of the model were evaluated, and the evaluating doctors filled in a questionnaire that contains 10 questions using a 7-points Likert scale [24] ranging from (1) Completely Disagree (2) Mostly Disagree (3) Slightly Disagree (4) Neutral (5) Slightly Agree (6) Mostly Agree to (7) Completely Agree.

Overall, all the answers were within 'agree' scales. Fig. 8 shows the summary of the results. 19% of the answers were 'Slightly Agree', 54% of the answers 'Mostly Agree' and 27% of the answers were 'Completely Agree'. This means that doctors agreed on the provided system but they had some comments regarding amendments required for:

- Anatomical relations of the different parts of the heart.
- Labelling.
- Anatomical information in the structures' list.
- Pathways of the conductive system for the heart.

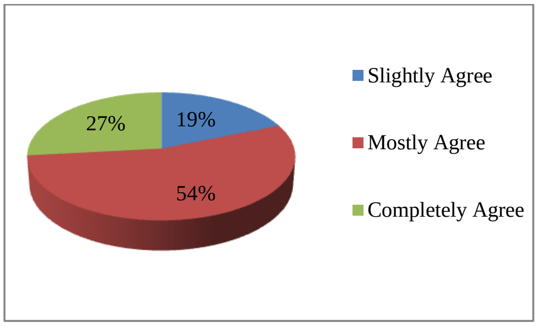

Fig. 8. Interface and VR Model optimisation results, all the answers were within 'Agree' scales

The aforementioned amendments were corrected which produced the final version of the system. The other type of the suggested amendments did not require changes in the system as the comments were regarding:

- Suggestions for more detailed anatomical information: the system already offers an 'Update' option for editing the information. This update may vary from one Faculty of Medicine to another. Therefore, this system has the major anatomical information that covers the heart anatomy, and the additional information was left up to the lecturers.
- Navigating and manipulating with the system: the variations in the answers were affected by personal preferences.

VII. Conclusion

The work presented within this paper proposed the design and development for the proposed educational aid which addresses daily issues for medical students in learning anatomy. The developed system was based on users' requirements and in depth medical doctors' consultations.

The system was developed to enhance medical education by utilising VR technology. Based on previous projects, VR has a potential to enhance visualisation, accessibility and training skills for medical doctors. Developing the VR Anatomy System for teaching anatomy will overcome the limitations of the traditional methods. Thus it aims to improve the medical education process.

Additional techniques have been utilised in order to enhance anatomy visualisation, for instance: providing interactive navigation through the heart model in different semi-immersive environments, adding additional navigational tools to improve model manipulation (rotating, enlarging, minimising, resetting, hiding, and highlighting), and providing anatomical information for each structure.

In addition to the consultations with medical doctors throughout the design and development stages, the alpha version of the system was evaluated. The evaluation was conducted by medical doctors covering several medical aspects, for instance, to ensure true anatomical relations of the different parts of the heart for the developed model, review the colour and texture of different parts and layers, and review the precision and consistency of the labelling and the anatomical information for the heart structures. Overall, the results were encouraging and only minor improvements were required that produced the final version of the system following users' feedback.

In summary, the VR Anatomy System aims to: improve the students' understanding of the anatomical information, facilitate accessibility to anatomical models in virtual environments, provide an assessment tool for both lecturers and students, and a teaching aid for lecturers that saves time and effort, and consequently enhances the medical education process.

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