3D Web-Based Anatomy Computer-Aided Learning Tools

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Abstract: *The advancements in computer graphics and the establishment of the world wide web as an ubiquitous repository of information have facilitated the creation of computer-aided learning tools that have wide accessibility. When such applications offer information about human anatomy, three-dimensional representations of such information are highly valuable to the learner in exploring the human organs in 3D and understanding the spatial relationships between them. This paper presents two computer-aided learning tools that utilize 3D web technologies to assist students in understanding human anatomy and physiology.*

Keywords: *Computer-aided learning, anatomy and physiology information, VRML, Java 3D, world wide web.*

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1. Introduction

Traditionally medical and biology students learn the human anatomy via anatomical atlas books and dissection. However, the atlas books are limited to the two dimensional space. Consequently students rely on their imaginations to understand the spatial relationships between structures. Furthermore, the increase in the number of students requires new methods of learning that provide wider accessibility. With the advancement of computer graphics, Computer-Aided Learning (CAL) tools have been developed to support students' learning of the human anatomy and physiology. One of the advantages of using CAL tools is that they make learning more attractive with the use of multimedia technologies. They also present different learning styles that suit various students (e. g., using text, sound, images, animations or simulation to explain the same concept). Students can learn according to their own pace. In addition, these tools can include self-assessment and feedback capabilities, which will indicate to students the amount of knowledge acquired. On the other hand, CAL tools reduce the load on teachers and allow them to accommodate large numbers of students [4].

Some of the CAL tools available for teaching human anatomy utilize data from real human Magnetic Resonance Imaging (MRI) or Computed Tomography (CT) scans or from the visible human data set [10], and use volume rendering or volume visualization to produce high quality 3D models of the human anatomy (e. g., VOXEL-MAN [11]). However, because of the high computations required by these tools, high-end specialized graphics workstations are required to run them. Hence, the use of such tools is confined to specialized labs and is not a feasible computer-aided learning solution for large numbers of students.

Recently, some developers of CAL applications have benefited from the wide use of the World Wide Web (WWW) as a source of information to provide wider accessibility to these applications.

In this paper, we will report two 3D computer-aided learning tools that can be used to assist students in learning the human body anatomy. The tools utilize Virtual Reality Modelling Language (VRML) and Java 3D technologies to facilitate wide accessibility via the WWW. In the next section we will review some of the related work in this area. Then, we will describe the first tool, which utilises VRML to teach the urinary system. Section 4 describes the second tool, which uses Java 3D to teach students the digestive system. Section 5 evaluates the tools and reports results of the user acceptability tests. Finally, we will conclude and look ahead towards future enhancements.

2. Related Work

Numerous computer-aided learning CDs exist in the market that teaches students the anatomy of the human body and varies in cost and the quality of the presented information. (e. g., Human Corporis Fabrica (HCF) [8] and A.D.A.M [1]). These tools utilize multimedia 2D images, animations and even 3D images in addition to text and sound to present the information in attractive easy to learn methods. However, very few of these tools offer the user an interactive experience with 3D models of the body organs. Furthermore, they are usually limited to the platform supported by the CD implementation.

Other tools that exist for teaching anatomy are Java applets that provide interactive navigation through cross-sectional images of human body organs (e. g., [5]). These tools provide three orthogonal image views (sagittal, coronal, and axial) of the organ with crosshairs to change the displayed cross-sections. Changes made to any of the three views are reflected on the other two. Such applets are limited to the 2D space of the cross-sectional images.

In [13, 14] a VRML-based anatomical visualization tool was presented, which provides a 3D surface model of the middle ear constructed from MRI data. The tool has the advantage of interactive 3D exploration of the model in addition to the options of changing colour and transparency of the model. It also provides 2D cross-sectional images superimposed on the 3D surface model with the ability to navigate across the 2D slices. However, because the tool was implemented in VRML 1.0, a special code had to be written for the transparency and superimposition features of the tool. Consequently, changing the cross-sectional slice or the scene parameters means contacting the server and waiting for the resulting model to come back across the network, which is not an interactive solution on the Internet environment.

The Digital Anatomist project done by the Structural Informatics Group (SIG) at the University of Washington is a repository of annotated 2D images and animation that are constructed from 3D data sets. It has two modes: quiz and browse modes. In the browse mode, you can navigate through the human body organs by clicking on small icons. Each image is annotated allowing the names and outlines of substructures to be obtained by clicking on them. The simple HTML interface that is used in the system makes it easy to use for non-computer professional students. However, the restriction of the repository to 2D images and animations prohibits the 3D exploration of the data sets. Consequently it limits the spatial understanding of the organs' relationships [12]. A similar system is the Human Anatomy Online web site, which provides a collection of 2D images of the body organs and their substructures. The system is implemented using Java applets [9].

The anatomy browser project done at the Surgical Planning Lab (SPL) developed a Java applet browser for human anatomy data sets, which are segmented from real MRI data. The browser displays 3D surface models of the organs, in addition to cross sectional slices and text information. Accessing the structures and substructures of the organs is possible through a hierarchical list provided on the browser. This list allows the user to view organs and their components either grouped or individually. The browser also provides cross-referencing between the three main parts of the application (the 3D model, the cross sectional images and the text information). The user has the ability to control the colour and opacity of the structures; however the implemented renderer of the 3D models allows only predefined viewer positions (top, left, right, bottom, front and back), which are pre-calculated from the data sets off-line [3,7]

The Cell-Tissue Human Body CD and website use VRML and Shout 3D to produce anatomical 3D models of body organs and animations of physiology. It is a very powerful educational tool that has been adopted in some schools. The design of the animations and the text information presented in the tool makes it useful as supporting teaching material in a biology course rather than an independent computer-aided learning tool [2].

3. Visualizing Anatomy Using VRML

The first CAL tool that we developed aims to assist high school students in learning the urinary system in their biology course. The tool consists of HTML pages with three frames that present information about the anatomy and physiology of the human urinary system. One frame includes the main menu containing hyperlinks to the urinary system components. The second frame provides Arabic text information about the chosen organ. The third frame provides annotated 2D images of the components. Navigation through the tool pages is either done using the main menu hyperlinks or the hotspot areas on the annotated 2D images (see Figure 1).

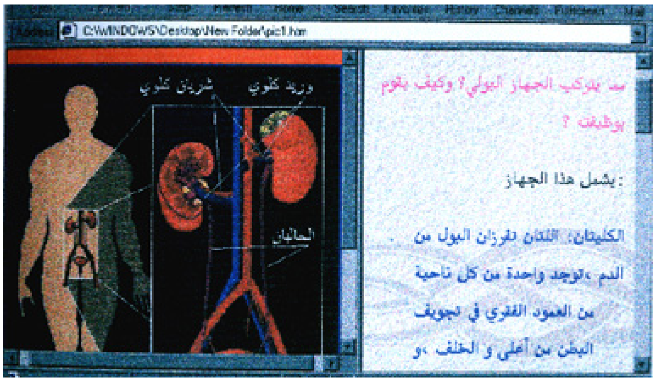

Figure 1. Annotated 2D images and text information frames in the urinary system CAL tool.

The tool also provides a 3D model of the nephron using VRML, which is considered the standard for the exchange of 3D information on the web. The anatomical model of the nephron was manually constructed using the sweep modelling technique, which is supported in VRML via the Extrusion node (see [15] for VRML specification). A circular cross section was used for the nephron model and the positions of the spine points were chosen based on a 2D image of the nephron (see Figure 2). In addition to the ability to explore the nephron model in 3D space (which is provided by default in the VRML browser), the tool provides animations to show the physiology of blood flow in the urinary system. One animation shows the production of urine out of the glomerulus towards the ureter. The second animation shows the blood flow into the nephron (in red colour) and out of it (in blue colour). Position and colour interpolator nodes from VRML were utilized to implement these animations.

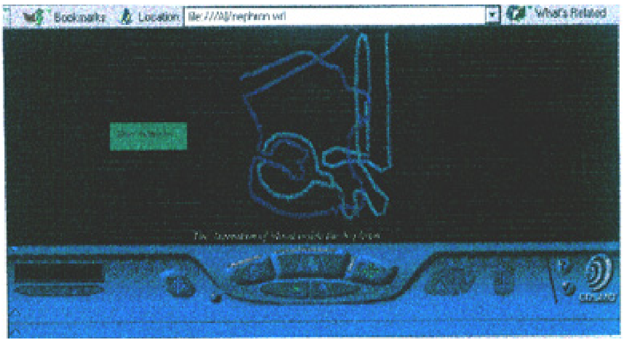

Figure 2. The 3D model of the nephron used in the animation of the blood flow.

4. Java 3D Digestive System Educational Tool

The second tool that we developed assists medical and biology students in learning the anatomy and physiology of the human digestive system. The tool utilizes the Java and Java 3D technologies to achieve a portable application. It includes text information, 2D images, 3D models, sound and 3D animations of physiology features. The tool also includes a quiz option to allow the students to self-assess their knowledge after using the tool. The questions are randomly selected from a database repository of questions. Access to the database is implemented using the Java DataBase Connectivity (JDBC).

4.1. 3D Anatomical Models

The 3D models of the organs used in the digestive system were obtained from different sources. The stomach, liver and pancreas models were manually constructed from 2D images. The images were used to extract 3D points that were then tessellated to produce polygonal models of the organs.

Meanwhile, the oesophagus model was constructed using the sweep modelling method in VRML. Then, the VRML file was converted to Java 3D using the Cyber Form conversion tool (http://cybergarage.org/vrml/cyberform/j3d/index.html). The rest of the models (e. g., small and large intestine and gall bladder) were obtained from the Internet in either VRML or 3Ds format and were converted to Java 3D.

4.2. Features and User Interface

The interface of the digestive system educational tool consists of five parts: a menu bar, a 3D panel, navigation buttons panel, a text information panel and a 2D image panel (see Figure 3). The menu bar and navigation buttons panel provide two different ways of accessing options provided in the system including organs in the digestive system and animations.

The 3D panel shows the 3D model of the selected organ, its lining or its subcomponents. To interact with the 3D model, the user can either use the left mouse button to freely rotate the model or use rotation buttons to rotate the model in four directions with a pre-specified angle. A home button resets the model to its initial orientation.

The text panel provides information about the selected organ, which can be printed as hardcopy or heard using sound files. Finally, the 2D image panel shows the chosen organ's position relative to the whole body.

The tool also provides 3D animations for the peristalsis motion in the oesophagus and digestion motion in the stomach. Both animations were implemented using the morph class in Java 3D, which interpolates between geometries specified as key frames.

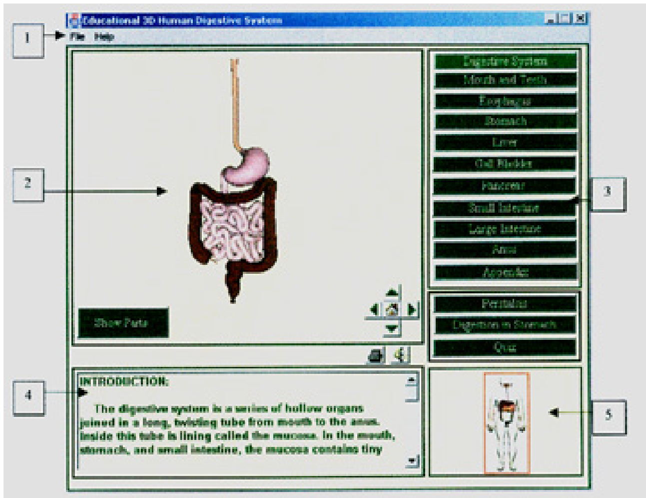

Figure 3. The graphical user interface of the digestive system CAL tool.

5. Evaluation

By utilizing VRML and Java 3D technologies in our tools, we have achieved one of our goals, which is providing large number of students with an accessible CAL tool. These technologies make it possible to exchange 3D information over the WWW without the need for specialised hardware. VRML requires a special plug-in, which is freely available on the web (http://www.cosmosoftware.com), while Java 3D only requires a Java enabled browser (Java runtime environment is also freely available from the Sun website (http://java.sun.com/products/plugin)). Both technologies do not require special graphics hardware to render scenes.

In order to support the student learning process, we provided information in multiple ways (e. g., text, images and sound). However, we were careful not to overload the user sensory system. For instance, the sound version of the text description of the organ in the digestive tool is available upon request using a special button that is included in all parts of the tool. The availability of sound should help our students in the pronunciation of the medical terms.

Text information provided in both tools was carefully chosen to suit the targeted audiences. In the urinary system VRML tool, our audience was high school students; hence the text was presented in Arabic and chosen from the high school biology textbook. Meanwhile, the digestive system tool targeted undergraduate students and the text information was chosen from the first biology course textbook.

The graphical user interfaces of the tools were designed to be easy to use for non-computer professional users. They depend on simple click buttons and include help instructions.

The most difficult stage in implementing both tools was obtaining the 3D models of the organs. We have used VRML and Java 3D geometry modelling techniques like the sweep and indexed surface to construct simple organ models as mentioned earlier. Some of these models can be enhanced (for instance the nephron model in the VRML tool) by increasing the number of points taken along the spine of the sweep model. In some cases models were found free on the WWW, but they were crude and too simple. Professional models do exist on some websites (e. g., [6]), but these are not free. Although the presented tools included simple 3D models, they were enough to achieve the purpose of assisting the targeted students in exploring and understanding the shapes of the human organs in 3D and their spatial relationships to each other. It is obvious that more specialized models based on realistic data sets (such as the visible human [10]) would be needed if the targeted audience was medical students.

The dynamic nature of both VRML and Java 3D technologies facilitated the inclusion of 3D animations showing the physiology of the human body. These animations show changes in colour and position (as in the blood flow inside the nephron) or morphing (as in the stomach and oesophagus animations).

A User acceptance test was conducted to evaluate the developed tools by asking the targeted students to fill a questionnaire after using the tools (26 subjects from biology and nutrition majors were tested). Results showed that all of the tested students thought that the tools were easy to use and an interesting way to learn the human body. Most of the tested students thought that the 3D animations showing the physiology of the human body were the most useful feature of the tools. Interestingly, about 10% of the students thought that the 3D models of the organs did not add much to their knowledge.

6. Conclusions

We have presented two prototypes for 3D computer-aided learning tools of the human body anatomy and physiology using VRML and Java 3D technologies. These 3D web technologies are very useful in supporting the understanding of the human body in three-dimensions and its structural spatial relationships. They also have the advantage of being widely accessible by a large number of students in different geographical locations through the Internet. In addition, these technologies do not require special graphics hardware, but they make use of them if available. On the other hand, this feature means (at least at the time of writing this paper) that one is limited to surface models rather than volume rendering.

The presented prototype tools have proven their feasibility and usefulness. The next step would be to take them to full-scale applications that provide a 3D atlas for the human body on the web. In order to achieve this goal, 3D models of the human organs need to be obtained.

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