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A Novel Virtual Reality Tool for Teaching Dynamic 3D Anatomy

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Abstract. A Virtual-Reality-based tool for teaching dynamic three-dimensional anatomy may impart better understanding of bone dynamics during body movement. One application of this teaching tool is radiographic positioning instruction. We propose Augmented Reality, a technology that allows the overlay of graphically generated objects(bones in this case) on the real scenes(body in this case), as a means of visualization for such an application. In this paper we describe the design and the three stages of development of a prototype unit which demonstrates elbow movement. Preliminary results and problems encountered while developing the first stage, are also presented.

1 Introduction

Virtual Reality (VR) tools are being developed for medical diagnostics and therapy, because of their extremely powerful, but non-invasive, three-dimensional(3D) visualization, which was hitherto unavailable. This paper describes a way to harness this power to better educate radiologic science students who currently struggle to visualize 3D bone movements using 2D teaching tools and stationary teaching models.

The current teaching methods for radiographic positioning include 1)2D photographs and radiographs; 2)Memorization of standard central ray centering points and degrees of beam angle; 3)Demonstrations that are passively watched by the students; 4)Videotapes, slides, audiotapes describing positioning methods; 5)Supervised positioning of real patients in clinical setting.

Not only do the students have to correlate all these inputs to what they know about the three dimensionality of the human body, but also form an understanding of the 3D dynamics of the bones when the model patient moves. These teaching methods have limitations such as: 1)None of the current physical models realistically simulate the alignment and movement of anatomical joints; 2)None of the current models teach the compensations for patients with limited range of movements; 3)And none of the current models effectively reinforce the connection between the patient's anatomical parts being imaged and the rest of the patient.

We speculate that an innovative and effective VR teaching tool could offer several advantages including: 1)Students will be better prepared for clinical work; 2)Students will learn through multiple senses (vision, touch etc.) which will reinforce their learning experience; 3)Students get an immediate feedback about the accuracy of the positions they create; 4)Model patients in the learning situation have no risk of radiation exposure or repeated attempts to position a part correctly; 5)There are no limits on repeating a given exercise several times. 6)This tool can be potentially expanded to work for any portion of the skeleton by appropriate modeling of the desired anatomy.

In this paper, a prototype of such a tool is described. This prototype is designed to demonstrate flexion, extension, pronation and supination movements of the elbow joint while maintaining a fixed humerus position.

After describing the elbow anatomy, then the concept of Augmented Reality, including how it derives its power, and the current problems are reviewed. This is followed by a description of the three stages of development of the first working prototype of the VR positioning tool. Finally, preliminary results and problems encountered while developing the test system are described. We conclude with a brief description of future work.

2 Anatomy

The prototype is currently restricted to the elbow joint. In the initial stage of the project, directed at demonstrating a proof of concept for future use in teaching radiographic positioning, only normal cases are considered(pathological cases such as tennis elbow, arthritis, congenital malformation etc. are not considered). The general description of a normal elbow joint, and some of the anatomical terms encountered elsewhere in this paper are presented in this section. For more details on anatomy see [1].

The articulation between the upper arm and the forearm is the elbow joint. It is a hinge type of joint, allowing mainly forward and backward movement. The bones involved in this joint are the humerus(in the upper-arm), radius and ulna(in the forearm), see Fig.1. The elbow joint includes a radioulnar articulation as well as articulations between the humerus and the radius and ulna. The three joints are enclosed in a common capsule at the elbow.

The lower part of the humerus is broad and has medial and lateral condyles and epicondyles, which are bulges on the sides. On its inferior surface are two elevations(trochlea and capitellum) for articulation with the forearm bones. On its posterior and anterior sides there are depressions to accommodate the processes of the ulna when the elbow is extended and flexed. The upper extremity of ulna presents a process called the olecranon process, which forms the semilunar notch at which it articulates with the trochlea of the humerus. The flat, disk-like head at the upper extremity of the radius rotates around the capitellum of the humerus and articulates with the radial notch of the ulna on the side.

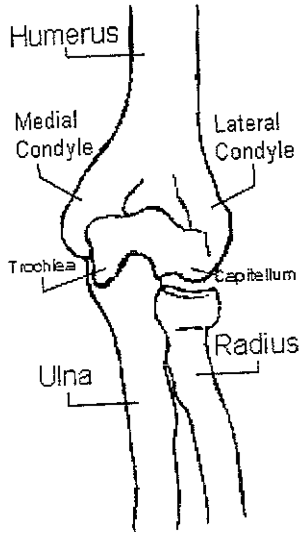

Fig. 1. Anterior aspect of elbow joint

The movements of supination (forearm outstretched with the palm facing up) and pronation (the forearm is twisted and palm facing down) of the forearm are largely the result of the combined rotary action of these two joints. In the act of pronation, the radius crosses over the ulna, while the ulna makes a slight counterrotation.

3 Augmented Reality as a New Tool

The Head Mounted Display(HMD) is a standard VR equipment. It is a helmet, worn by the user, mounted with two miniature displays, one for each eye, and a head position tracker. Stereoscopic images of the scenes of interest are painted on the displays and updated in realtime by a computer based on the position and orientation information provided by the tracker. Usually HMDs are opaque, i.e. only the computer generated graphics are visible, we call this full VR. Alternatively, the HMDs maybe see-thru. In which case the real world view is also available in addition to the computer graphics. One refers to the technique of superimposition of real and virtual information using a see-thru HMD as "Augmented Reality". If the real scene is presented as a video image then the HMD is termed "video see-thru"[2], else, if the real world is presented optically, then it is termed "optical see-thru" [3].

Based on our experience with developing see-thru HMDs and AR systems at the University of North Carolina at Chapel Hill [2], [10], it is felt that AR systems are extremely well suited for medical applications. However, research [3] [5] [10] has shown that many challenges specific to AR need to be surmounted, in addition to the problems of full VR. By far the most important one is the registration of the real image with that of the virtual one. A major component of this task is the calibration of the HMD [3].

4 VR Positioning Tool, the Scheme

The VR positioning tool will be developed in three stages, which differ in the display modality used.

- The objective of the first stage is to achieve proper modeling of motion of the bones in the elbow joint. Only the graphics will be displayed(monoscopically). No stereo will be involved.
- The second stage involves the use of Enhanced Reality for visualization. Here, the real scene is captured by a small TV camera and is displayed superimposed with the "enhancing" graphics on a flat display. The difference from the video see-thru being that the display is not stereo and no head tracking is done. This stage will enable proper testing of tracking and registration. We anticipate that the calibration problems encountered here will be common to in the next stage and hence the experience beneficial.
- Finally, in the third stage, we plan to use an optical see-thru HMD, where, instead of using video cameras, an optical viewer will merge the real and virtual scenes.

5 Apparatus

The apparatus used in the various stages of the development includes magnetic trackers, an Enhanced Reality setup used at an early stage of the prototype development and a bench prototype of the see-thru HMD that will serve as the final visualization tool of the first prototype. A good discussion on VR technology can be found in[6].

Tracker. An extended range Flock of Birds magnetic tracker developed by Ascension Technology [8] is being used to track the patient's arm movement in the second and third stages. Specifications of the tracker can be obtained in [9]. The tracker uses one transmitter and three receivers placed, one near the extremity of the humerus, close to the forearm, and two at either end of the forearm. Using the position information obtained from the trackers, the current position of the bones in the world computed and immediately displayed. To model just the flexion and extension of the arm, only one forearm receiver suffices, two of them are needed to capture the displacement of radius and ulna with respect to each other when pronation and supination take place. The receivers are mounted as accurately as possible on or around some major anatomical landmarks(eg. condyles) to enable accurate registration. They are fastened firmly to prevent sliding along the arm. However, unless the receivers can be surgically implanted on the bones themselves, the stretching of the skin will cause inconsistencies.

Enhanced Reality Setup. It will be used for the second stage. The difference from the first stage is in the visualization mechanism. Here, the graphics are superimposed over a video of the real scene captured by a miniature camera appropriately placed to simulate one of the observer's eyes. The superimposition of the graphics on the video is done in realtime.

Optical See-Thru HMD. A Bench setup of an optical see thru HMD, with no allowable head motion, will be used in the final stage, see Fig.2. The benefits of using a bench prototype comes from not being penalized by another component of tracking delay due to the head tracker. The displays are driven by an SGI Onyx's Multi Channel Option which provides two separate channels.

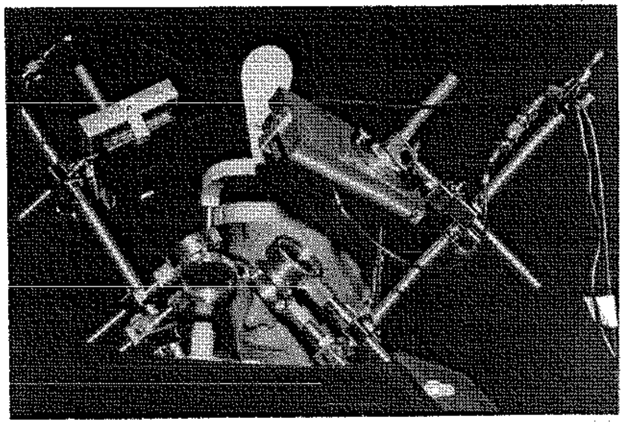

Fig. 2. The bench prototype of optical see-thru head-mounted display

6 Preliminary Results of Developing the First Stage

The major portion of the implementation of the first stage involves modeling and rendering the bones and their motion so that they can be reproduced by graphics and presented as virtual objects in the HMD. The various modeling that has been done for the first stage is presented in this section.

In the first stage, the software simply animates the graphic bones according to the motion model described previously. This stage enabled us to validate the motion model.

6.1 Modeling and Rendering of the Anatomy

A commercially available model of the bones was obtained from Viewpoint [11]. The bones were modeled as lists of polygons with a normal at each vertex. A low-resolution model with 690 vertices and 472 polygons was used. The Viewpoint model was arrived at by digitizing a representative set of bones of a specific size.

There is a wide variation in the various aspects of anatomy, not only by gender, but also among individuals of the same gender. For example, women tend to have, in general, shorter bones than men. Also, the angle subtended by the forearm to the line passing through the humerus is generally greater for women than for men.

This wide variation implies that separate modeling be done for each patient, and this provides a logistic difficulty. To avoid this problem, the model uses a unique polygonal model which is scaled appropriately to match the patient. Also, only a small subset of variation about the norms for a single sex is modeled.

An x-ray of the patient's arm was used to compute the correct scaling factor. This is achieved by applying the process of registration of the bone images obtained by x-ray with the rendered image of the computer model.

The rendering was done on an SGI ONYX platform using the OpenGL [7] library. Two views (one for each eye) were rendered in different areas of the screen for the Multi-Channel Option (video splitting mechanism provided by SGI) hardware to capture and generate from them, two different signals.

6.2 Modeling Motion

There are two elements to motion modeling of the joint: 1)dynamics and 2)kinematics. Dynamics involve modeling the various forces and the accompanying deformations that are involved during motion. Whereas, the kinematics is an aspect of dynamics which deals with aspects of motion apart from considerations of mass and forces. In the case where the arm is flexed very quickly, there are some impulse forces involved which cause some spurious motion. However, when the arm is flexed slowly, the forces involved in the joint can be considered to be at equilibrium. Hence, while modeling motion, only the kinematic aspects of the bone are considered.

Firstly, a skeleton of the arm was used to reach a better understanding of the anatomy involved. Fluoroscopy was used to deliver a good understanding of the motions of the various joint components. The pivotal points and axes were then identified using knowledge of physical anatomy and the corresponding points were located on the bone model. The following useful information about the motion was derived in this process.

- The main axis about which the ulna rotates when the arm is flexed lies roughly through the middle of the two condyles of the humerus.
- During the twisting motion (supination and pronation) the ulna rotates about an axis passing through its shaft and its head touches the trochlea of the humerus.
- In the same twisting motions, the head of the radius moves along the capitellum of the humerus, however its axis lies outside the shaft resulting in the crossover with the ulna. This axis changes too.

7 Discussion and Conclusion

The biggest stumbling block is the speed and accuracy of the tracker. Since the virtuals objects interact with the real world, the requirements on the positions are extremely strict to obtain proper registration. We hope to solve this problem by a proper motion model. The use of generic bones causes another problem since anatomy differs between people. Currently this problem is avoided by limiting the model to work for only a small subset of the possible range.

Currently, the system is in the first stage of development (ref. Sec. 4). We plan to enhance the visualization modality in two more stages as mentioned before. The current CS graph used by the program accounts for the flexion and extension motions so far. It needs to be extended to utilize the input from the second forearm receiver to model the twisting motions of the forearm. Finally, work has to be done to model the motion more accurately (this can be better understood only when the second stage of development is completed).

In this paper we have summarized the drawbacks of current teaching methods for radiographic positioning and described the concepts of a novel VR tool for teaching dynamic 3D anatomy. Different issues involving the merging of real and virtual worlds were briefly presented. The proposed three stages of a first prototype as well as its components were discussed. Preliminary results of the modeling and implementation of the first stage were presented. Finally, it is concluded with a brief discussion and a look ahead at the future work.

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