THE VIRTUAL HAPTIC BACK PROJECT

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Abstract

This paper discusses the Ohio University Virtual Haptic Back (VHB) project, including motivation, implementation, and initial evaluations. Haptics is the science of human tactile sensation and a haptic interface provides force and touch feedback to the user from virtual reality. The VHB combines high-fidelity computer graphics with haptic feedback to augment training in palpatory diagnosis in Osteopathic medicine, plus related training applications in physical therapy, massage therapy, and other tactile fields. We use the PHANToM haptic interface to provide position interactions by the trainee, with accompanying force feedback to simulate the back of a live human subject in real-time. Our simulation is intended to add a measurable, repeatable component of science to the art of palpatory diagnosis. Based on our experiences in the lab to date, we believe that haptics-augmented computer models have great potential for improving training in the future, for various tactile applications. Our main project goals are to: 1. Provide a novel tool for palpatory diagnosis training; and 2. Improve the state-of-the-art in haptics and graphics applied to virtual anatomy.

Introduction

Haptics, the science of touch, is being applied in virtual reality environments to increase realism. An example of this is virtual reality computer games that use a force-reflecting joystick.

Haptics has been applied recently to education, most notably in medical education. In the Stanford Visible Female project (Heinrichs, et al., 2000), a 3D stereoscopic visualization of the female pelvis has been developed from numerous slices of 2D pelvis data. Further, haptic feedback was enabled via the PHANToM haptic interface, allowing the user to interact with and feel the virtual model. The Interventional Cardiology Training Simulator (Shaffer et al., 1999) links technical simulation with specific medical education content. A virtual reality-based simulator prototype for the diagnosis of prostate cancer has been developed using the PHANToM haptic interface (Burdea et al., 1999). An earlier tumor palpation VR simulation was developed by Langrana (1997). The Immersion Corp. (www.immersion.com) has developed haptic interfaces for injection training and sinus surgery simulation. Delingette (1998) is working on realism in modeling human tissue for medical purposes. The GROPE Project (Brooks et al., 1990) has developed over 30 years a 6D haptic/VR simulation of molecular docking. The SPIDAR haptic interface has been adapted to serve as "the next generation education system" (Cai et al., 1997), although the authors do not elaborate on the type of education intended.

A group at the University of Ioannina in Greece is involved with virtual learning environments including a Power Glove with tactile feedback to "build a theoretical model for virtual learning environments, expanding constructivism and combining it with experiential learning" (Mikropoulos and Nikolou, 1996). A research group at the Ohio Supercomputing Center has applied haptics in virtual environments to improve tractor safety by training young rural drivers (Stredney et al., 1998); their results show haptics increases training effectiveness. Haptics has been applied to make virtual environments accessible to blind persons (Jansson et al., 1999). Affordable haptic interfaces have been implemented to augment the teaching and learning of high school physics (Williams et al., 2001). High-end haptic devices have been applied for force-reflecting robotic teleoperation, e.g. Williams et al. (1998). This literature review demonstrates the significant interest in the field of

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haptics and graphics for biomedical applications; our work is unique because of its Osteopathic Medicine focus and emphasis on palpatory training.

The Virtual Haptic Back (VHB) project is an interdisciplinary collaboration between two Ohio University colleges: Engineering and Osteopathic Medicine. Its purpose is to develop a realistic haptic/graphical model of the human back that can be used for palpation in medical training, as a step toward a more comprehensive haptic modeling of the human body. The VHB will add a component of science into the learning of the art of palpatory diagnosis. It has the potential to be the flight simulator equivalent for learning palpatory diagnosis for Osteopathic Medicine, Physical Therapy, Massage Therapy, and related fields.

In addition to the two project goals stated in the Abstract, another overall project goal is to investigate the effectiveness (including cost-effectiveness) of haptics in virtual environments. Our work will support technology developers, applications developers and users in the future.

The current VHB model is shown in Figure 1. The blue cursor indicates the virtual location of the palpator's finger; via the PHANToM haptic interface (Figure 2), the trainee can move about this model, while feeling a simulated live human patient.

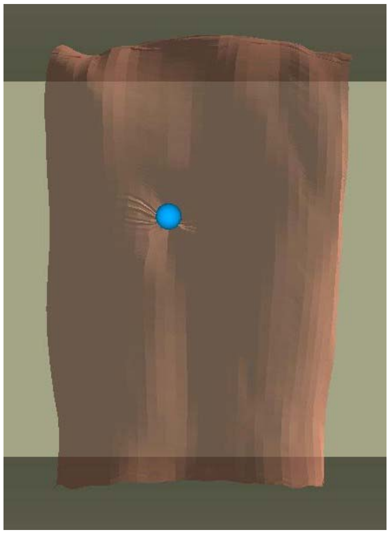

Figure 1. VHB Model

Figure 2. PHANToM ™ Haptic Interface

This paper presents motivation, overview, and details for our VHB model. We then present a summary of evaluations to date plus future evaluation plans and a discussion of the potential role of haptics in training.

VHB Motivation and Overview

The purpose of the VHB project is to develop a series of computer-based, haptic simulations of the human body to assist students in the learning of palpatory techniques.

From the very beginnings of medicine, palpation (diagnosis through touch) has been an important part of the diagnostic process, for detection of organ enlargement, tumors, herniations, tissue swelling, and of abnormalities in the movements of heart, lungs, intestines, muscles, bones, and joints. Palpation has been an additionally significant part of Osteopathic medical practice, because of its emphasis on somatic dysfunction and viscerosomatic reflexes. Palpation is an effective, sensitive, and economical way to diagnose many musculoskeletal (somatic) dysfunctions, including those that arise from visceral abnormalities via viscerosomatic reflexes. Unfortunately, the diagnosis of dysfunction by means of palpation is difficult to learn for three reasons: Palpation requires a highly trained sense of touch; medical students generally practice on each other, thus the subjects are often young and healthy; palpation on a human subject may change conditions, hence successive students may not be presented the same case to feel. Virtual reality with haptic feedback shows promise for overcoming these obstacles in palpatory training. Each of these difficulties can be addressed by the VHB simulator. Haptics provides the opportunity for practice to develop the sense of touch on simulated somatic dysfunction of graded intensity, presented in a reproducible way. Our simulator also provides a means for an instructor to keep track of and rate the progress of each trainee.

VHB Product

The VHB is under development to simulate the palpatory feel of the normal and the dysfunctional human back. A high-fidelity graphical model of the human back (Figures 1 and 9) is coupled with a haptic interface (Figures 2 and 12) to allow user interaction.

Model Evolution

The back of a volunteer subject (adult male of average size) was measured using a Metrecom Skeletal Analysis System (SAS) made by Faro Technologies Inc (see Figure 3). An offline graphical representation of the smoothed data from this original model is shown in Figure 4.

In the initial real-time interactive model version, *v*0, (shown in Figure 5) the feel consists of linear springs of varying spring stiffnesses, normal to the surface of each graphical polygon. As shown in Figure 6, a more complex haptic model was then developed wherein a cylinder with simulated ribs is encased in a sphere of fleshy material. The idea behind this model is to allow the user to feel different layers of haptic feedback (i.e. palpate through the fleshy material to feel the ribs beneath the surface). Figure 7 shows the first interactive VHB model, *v*1, that includes this layered feature, plus a model of the human spine.

Figure 3. SAS

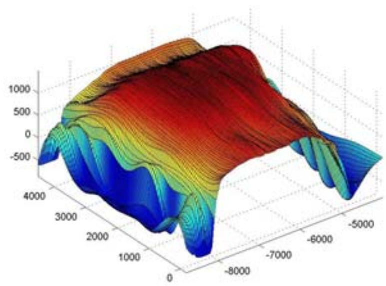

Figure 4. Smoothed Back Data

Figure 5. Initial Back Model, v0

An improved back model, *v*2, is shown in Figure 8. This VHB model shares the same attributes as *v*1, but the graphics and haptics properties have been improved. Also, a new subject back was measured, including the major skeletal landmarks for increased realism. The circles located laterally represent the acromion process above and the posterior superior iliac spine below.

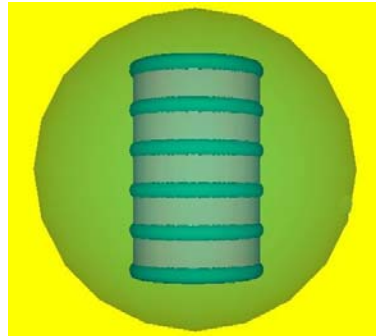

Figure 6. Layered Haptic Model

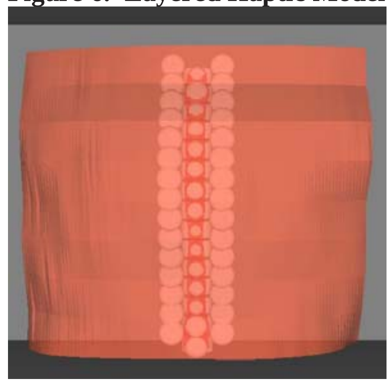

Figure 7. VHB, v1

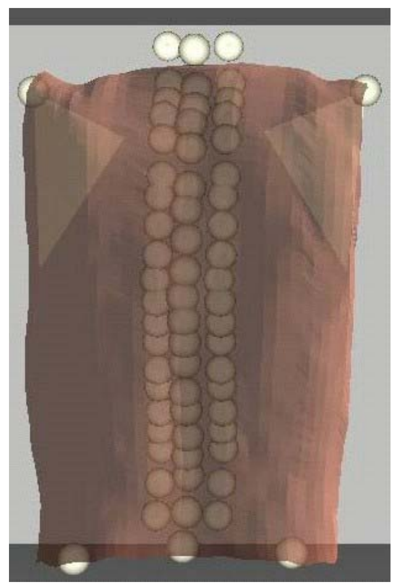

Figure 8. VHB, v2

The current VHB, *v*3, is shown in Figure 9. This model, an extension of *v*2, has two new features. First, movable haptic ribs have been added. Second, for the first time, two PHANToM haptic interfaces are implemented for dual-handed palpation (L and R cursors in Figure 9; the two PHANToMs are pictured in Figure 12).

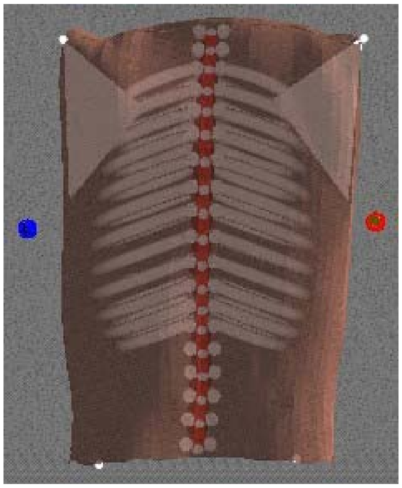

Figure 9. VHB, v3

For more information, and future updates, please visit our VHB website:
http://www.ent.ohiou.edu/~bobw/html/VHB.html.

Hardware

The PHANToM haptic interface (Figure 2) by SenseAble Technologies, Inc. uses position information input by the user to determine what forces to relay back to the user via its three motors. A flow diagram for the PHANToM is pictured in Figure 10. The human finger moves the PHANToM to desired X, Y, Z Cartesian locations (sensed internally via joint encoders $\theta_1, \theta_2, \theta_3$); this Cartesian input is sent to a virtual computer model. The haptic/graphical software determines what Cartesian force vector F_X, F_Y, F_Z the human should feel and the PHANToM generates this force at the human finger (accomplished internally via joint torques τ_1, τ_2, τ_3).

Figure 10. PHANToM Flow Diagram

The PHANToM 1.0 shown in Figure 2 has a nominal resolution of 0.03 *mm*, a workspace of 13x18x25 *cm*, and a maximum exertable force of 8.5 *N*. Our PHANToM only reads positions and exerts translational forces; a passive gimbal connects the user's finger to the tip of the PHANToM.

The VHB simulation runs on a 900 MHz, dual processor PC NT workstation, with a Matrox Millennium 6400, 32 MB graphics card.

Software

SensAble Technologies Inc. provides a General Haptics Open Software Toolkit (GHOST® SDK). It is a C++ object oriented toolkit that represents the haptic environment as a hierarchical collection of geometric objects and spatial effects. The Ghost® SDK uses OpenGL and 3D graphics. The 1000 *Hz* servo loop perform the following functions:

1. Updates the PHANToM node position in the scene.
2. Updates the dynamic state of all dynamic objects.
3. Detects collisions in the scene.
4. Sends the resultant force back to the PHANToM.

Haptics Model

The haptics feedback in the VHB is the result of a combination of different models. The vertebra and bony landmarks were created with SensAble Technologies GHOST software. Their haptics are modeled by a spring-damper system. The motors in the PHANToM limit how solid these objects will feel. The spinous ligament is created as a mesh object, again using the GHOST software. The stiffness of the mesh is set slightly lower than that of the vertebra. The feel of the mesh is also modeled by a spring-damper system. The skin is made up of two parts. The first is a mesh similar to the spinous ligament. Once a certain force threshold is exceeded, the user will push through this mesh into a second force region. This part of the skin uses a surface model. The feel of the skin in this region is determined by a linear function of the distance from the surface of the skin to the position of the user below the skin surface. The model is layered because the vertebrae, spinous ligament and bony landmarks are located within the skin force field. As these objects are being touched, the second skin force is pushing the user away from them.

The values for spring stiffnesses for the skin and bone models, plus the rotational stiffnesses for the vertebrae were not measured from a live human subject. Rather, they were set by the development team according to subjective feel. We have been updating these values based on expert feedback for increased realism.

Features

The VHB is being developed as a device for use in teaching medical palpatory skills. The operator feels resistance as the finger touches the simulated skin. As the finger is pressed into the skin, the vertebral spines or transverse processes can be felt as additional resistance sensed by the palpating finger. An image of the back being palpated appears on a computer screen along with a cursor that specifies location of the palpating finger. As the finger compresses the skin, the skin can be seen on the screen to dimple. The graphics can be set to reveal the underlying bone or not, so that the palpation can be done with or without the aid of seeing the underlying vertebrae on the screen (the real world does not allow this choice!).

The VHB, v1 (Figure 7) included only vertebral spinous processes C6 through L1; these were fixed so the user could palpate each, but there was no relative motion. The VHB, v2 (Figure 8) improves upon this, including vertebral spinous processes C2, C6, and C7, T1 through T12, and L1 through L5. Version 2 skips cervical vertebrae C3 through C5 because they are so close together. Individual vertebrae T1 through T12 can be rotated as the operator presses on a transverse process, as shown in the close-up view of Figure 11 (sixth down from the top). The resistance to rotation can be varied for each of these vertebra independently so as to simulate restricted vertebral motion. The initial position of each of these vertebra can also be set independently via a pull-down menu in order to simulate vertebrae out of position. The VHB, v3 (Figure 9) shares the same attributes, with the addition of movable haptic ribs.

Figure 11. Vertebra Rotation

The interspinous ligaments joining the spinous processes are palpated as objects with less intrinsic stiffness (more give) than the spinous processes. Transverse processes can also be palpated lateral to the spinous processes and deeper. These features allow instructors to program various somatic dysfunctions, using pull-down menus. Students can then be asked to detect these abnormalities by palpation.

The system is still under development and will be expanded in the future to include ribs, different axes of rotation for more of the spinous processes (currently these rotate only about the axis of the spine), soft tissue changes, such as muscles in spasm and regions of local edema, plus two handed palpation via the new PHANToMs pictured in Figure 12.

Figure 12. PHANToMs for Dual-Handed Palpation

The two PHANToM 3.0 haptic interfaces shown in Figure 12 have nominal resolution of 0.02 *mm*, a workspace of 39x54x75 *cm*, and a maximum exertable force of 22 *N*. Again, these PHANToMs only read positions and exert translational forces; a passive gimbal connects the user's finger to the tip of the PHANToM.

The updated VHB simulation with two PHANToMs runs on a 2.8 GHz, dual Pentium Xeon processor PC NT workstation, with 1 GB RAM and a NVIDA Quadro4 900XGL, 128 MB graphics card.

Sound feedback is employed in the simulation to provide immediate feedback to the trainee during palpatory diagnosis practice sessions. When the trainee has identified the spinous process that is out of place, for instance, pressing a button will provide aural feedback as to if the identified one is correct.

We have also implemented a playback feature wherein an expert's motions during a simulated VHB diagnosis can be saved and replayed later for trainees using the PHANToM haptic interface. In this way the steps taken by an experienced practitioner of manual medicine can serve as a guide to a learner. Figure 13 shows two position trajectory curves, the red one representing the expert's recorded positions and the green one showing the path traced by the PHANToM upon playback to a trainee.

The closeness exhibited in Figure 13 between the expert's motions and the playback experienced by the trainee indicates that we may use this developed feature in our work with small position errors.

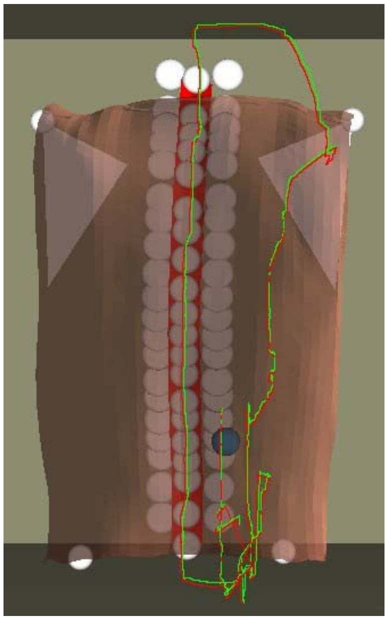

Figure 13. Playback and Recorded Paths

Figure 14. Expert/Student Evaluation in the Lab

Evaluation Plan

This section presents our initial VHB evaluations, plus plans for continuous evaluation as the project progresses. This section concludes with a brief discussion on the potential of haptics-augmented graphical images in training applications.

Our initial VHB evaluations have taken two forms. First, from the start we have sought expert Osteopathic Doctors' advice in improving the realism of our simulation. Many of their comments have been implemented in the current simulation, *v*2. This type of feedback will be continuously sought and acted upon as the VHB evolves. In our first formal evaluation, a group of physical therapy graduate students and a control group of engineering students were asked to practice with and rate the effectiveness of the VHB with regard to the quality and realism of graphics and haptics. The current simulation also reflects the results of this initial evaluation.

The current instantiation of the VHB is shown Figure 9 (transparent, showing the underlying skeletal structure; this transparency can be turned off). Figure 14 below shows expert/student evaluation of the VHB simulation in the Osteopathic Manipulation Laboratory at Ohio University (the live human subject is optional). We have plans for four consecutive, continuous evaluations of the VHB model, using Osteopathic medical students at Ohio University, for two years each. A second group for each of the four evaluations will be a control group of Osteopathic medical students having no exposure to the VHB.

The primary hypothesis to be tested will be:

"*Experience with the Virtual Haptic Back will significantly aid in the learning of palpatory skills by osteopathic students*."

A secondary hypothesis to be tested will be:

"*The Virtual Haptic Back may also provide an objective means for testing palpatory skills*."

Future training evaluation using the VHB will involve somatic dysfunction. The goal is to provide realistic somatic dysfunction for the trainee to identify through palpation with the virtual model; this can be done in a repeatable manner, with as much practice as the trainee desires.

Finally, our preliminary laboratory experiences indicate a great potential future for haptics-augmented virtual reality simulations in training applications. Though our work is relatively narrowly focused on palpatory training for medical and related fields, we can see the potential for training in general tactile tasks. We say: "*Feeling is believing!*" Combining realistic, real-time haptic feedback with high-quality real-time interactive computer graphics will be a powerful tool in future training applications in many fields. Many diverse areas may be served with similar haptics-augmented training technologies. We believe that such tools will lead to more natural, fun training with deeper understanding and more retention compared to current methods without tactile feedback. Not only can specific training applications be improved, but such tools would tend to improve the underdeveloped human tactile sense in general.

Conclusion

We present an overview of the Virtual Haptic Back (VHB) project at Ohio University. This project is under development to augment tactile training in Osteopathic medicine, physical therapy, massage therapy, and related fields. Our simulation involves a high-quality computer graphics model implemented with a haptic interface. The user interacts with the simulation via the haptic interface in real-time, moving the tip of the PHANToM to navigate around the simulated live human back, while feeling appropriate realistic haptic feedback. We have a layered haptic model wherein the palpatory trainee can feel the skin, plus underlying tissue, skeletal structure, and ligaments. Pull-down menus are used to establish simulated somatic dysfunction, setting different initial positions and relative stiffnesses for the various spinous processes. The model can be viewed either opaque, as in the real world, or transparent for easier interaction during early practice. Sound feedback is included to assist the trainee and a playback mode has been developed to demonstrate to the trainee an expert's approach to the same palpatory diagnosis problem. The VHB model adds a measurable, repeatable component of science to the art of palpatory diagnosis.

This paper describes the VHB simulation, discusses our initial evaluations and future evaluation plans, and presents a discussion of the potential of haptics-augmented training systems. Early evaluation results indicate a good potential for our tool in palpatory diagnosis training. This work is a first step in our large future goal, 'Virtual Haptic Anatomy', which will deal with the entire virtual human body, with realistic haptic sensations, both inside and out.

Acknowledgements

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Author Biographies

Robert L Williams II, associate professor, has been in the Department of Mechanical Engineering at Ohio University for eight years. Previously he was employed for five years as space roboticist at NASA Langley Research Center. He earned the Ph.D. in Mechanical Engineering from Virginia Tech. Dr. Williams has research interests in robotics and virtual reality. He is especially interested in haptics with graphics for simulation, training, and education.

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John N. Howell, Ph.D. from UCLA in 1968, is a physiologist with special interests in skeletal muscle function. He has been at the Ohio University College of Osteopathic Medicine for 25 years, where, as director of the Somatic Dysfunction Research Institute, he has carried out studies of exercise-induced muscle injury and the effects of manipulative treatment on somatic dysfunction.

Robert Conatser, M.S. in Physics from Ohio University, has been a research associate with the Somatic Dysfunction Research Institute for 13 years. He is interested in the design and analysis of research studies with human subjects.