Evaluation of the PHANToM Playback Capability

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ABSTRACT

This article presents implementation and evaluation of a position and force haptic playback system for the PHANToM haptic interface, in the context of our Virtual Haptic Back Project at Ohio University. Playback has the potential to improve virtual palpatory diagnosis training by allowing students to follow and feel an expert's motions prior to performing their own palpatory tasks. No human factors data is presented; rather, this article studies the performance and implementation of our playback system, in terms of how faithful the reproduction of recorded position and force is. We experimentally study the position and force errors upon playback, as a function of our playback parameters: spring stiffness *k* and zero force radius *r*. Position error decreases with increased *k* and decreased *r*. However, one cannot increase *k* or decrease *r* indefinitely as an unacceptable buzzing effect arises. Force error is not much affected by different *k* and *r*.

1. INTRODUCTION

The Virtual Haptic Back is under development at Ohio University to augment the palpatory training of Osteopathic Medical Students and Physical Therapy and Massage Therapy students (Holland et al., 2002). This project has implemented a high-fidelity graphical and haptic model of the human back on a PC, using the PHANToM interface for haptic feedback.

The current article focuses on the implementation and performance of our PHANToM playback feature, motivated by training needs in the Virtual Haptic Back Project at Ohio University. This article presents position and force error data in PHANToM playback in the Virtual Haptic Back context. This article first presents a brief overview of the Virtual Haptic back, followed by a description of our PHANToM playback capability, and then presentation and discussion of our playback system experiments and results.

2. THE VIRTUAL HAPTIC BACK

A virtual back graphics model has been developed, based on measurements taken with a 3D digitizer. Haptic feedback has been programmed, associated with this virtual back model via the PHANToM haptic interface (Fig. 2, Massie and Salisbury, 1994, also http://www.sensable.com/ .

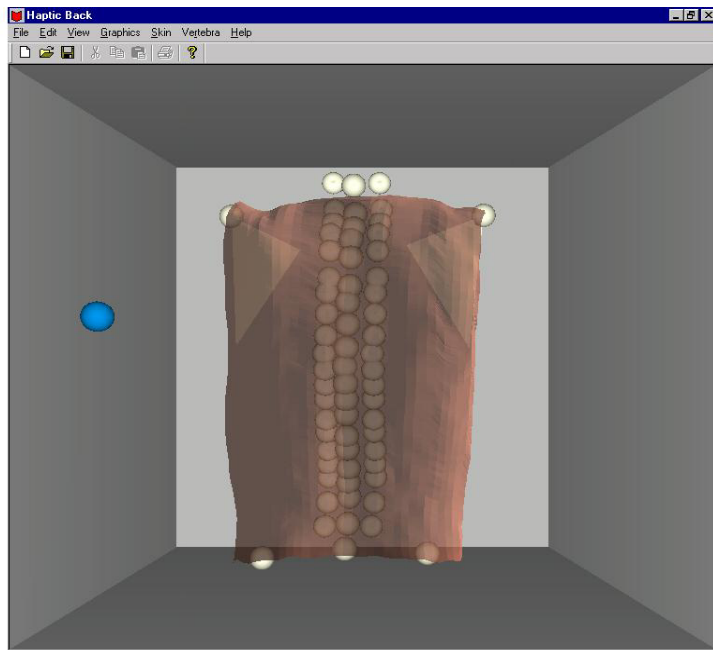

FIGURE 1. THE VIRTUAL HAPTIC BACK

The virtual back consists of skin, a spine (C2 at top then C6 through L5), interspinous ligament, scapulae, acromion processes and PSIS (posterior superior iliac spine). In using the
Virtual Haptic Back, the student first encounters resistance from compression of the skin and then additional resistances representing underlying bone. 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. Each vertebra can rotate in response to pressure applied by the operator to the transverse processes. The resistance to rotation can be set independently for each vertebra. The initial position of each vertebra can also be set independently via menu. 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 vertebrae on the screen (the real world does not allow this choice!).

3. PLAYBACK SYSTEM

In a paper on diagnosing prostate cancer (Burdea et al., 1999), the PHANToM playback mode is used both to analyze a trainee's performance and to show the trainee how an expert approaches prostrate examinations. The same research group is applying general graphics playback in palpation training for detecting subsurface tumors (Dinsmore et al., 1997). In this paper, a data file is written with all inputs from all I/O devices to replay the user's actions graphically. This case does not involve the PHANToM with haptic playback. A second group is using the PHANToM playback feature in their horse ovary palpation simulator (Crossan et al., 2000), to implement a tutor/trainee model.

We have developed a haptic playback system wherein user's position and force interactions with a haptic model may be saved and played back to the PHANToM. This haptic playback has two versions, one in which the recorded interaction forces are played back and the haptic model is turned off and the other in which the recorded forces are not sent but the haptic model is turned on, i.e. we make the PHANToM trace the user's previous path and forces are felt due to the PHANToM interacting with the haptic objects.

To achieve playback in the Virtual Haptic Back, two data files are created during the recording mode. One file records the *XYZ* positions of the PHANToM and the other records its F_X, F_Y, and F_Z reaction forces. In the original simulation the input comes from the user's hand motions, via the PHANToM encoders. In playback the input is read from the data files; the position playback is achieved as described below.

Position Playback. For recording the user's path, points are sampled at a rate of 1000 *Hz*, and saved in a binary text file. These points are read and the PHANToM playback driving force F is calculated using (1). This driving force moves the tip of the PHANToM back through the previously-recorded positions for playback.

$$F = k\left(\|v\| - r\right)\left(\frac{1}{\|v\|}\right)v \qquad (1)$$

In (1), k is the virtual spring constant; v is the vector distance between the current PHANToM position and the next playback point to move to (the center of an attractive spherical force field, see Fig. 2). r is the radius of the spherical region in which there is no force.

The center of the spherical attractive force field is initially located at the PHANToM tip so the PHANToM is within the no-force region. The PHANToM has some play in this spherical no-force region, so r should be small for small position error. The force field is then shifted to the next recorded position. As this is done the PHANToM is moved out of the no-force region. The driving force (1), proportional to the distance $v–r$, acts on the PHANToM and attracts it to the zero force region of the shifted force field. The force field is then shifted to the next recorded position and this loop repeats until the end of the playback file is reached.

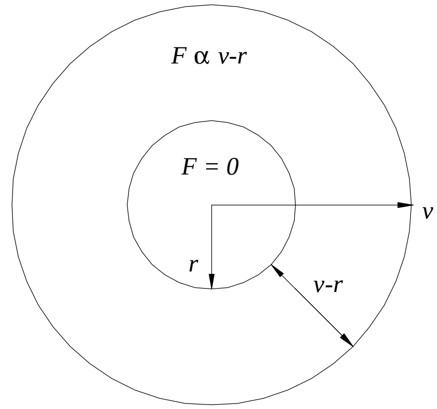

Figure 2. Spherical Attractive Force Field for Position Playback

Force Playback. During the recording mode all the PHANToM reaction forces are saved to a data file in binary mode. To achieve force feedback during playback, a force field of sufficiently large volume to cover the volume of the haptics-enabled region on the screen is created. The reaction forces are then read and sent to the PHANToM to get the playback force.

4. PLAYBACK EVALUATION RESULTS

This section presents the playback experiments and the results obtained. Four different cases were considered: with and without the human finger in the PHANToM thimble and with and without the recorded force with corresponding haptics model disabled and enabled, respectively. We will present here results for without finger case only.

For the experiment an arbitrary path of approximately one minute duration was chosen, with 41,957 path points. The path was made to interact with the virtual human skin, spine, interspinous ligaments, and the scapula. In order to compare the effectiveness of the system under different values of k and r, the same path is used for all cases.

The difference between the recorded force and position and those obtained during playback is calculated in the X, Y, Z directions. In this article, a mean square error (*MSE*) measure is used for both force and position:

$$MSE = \frac{\sum_{i=1}^{n} \sqrt{(X_{iR} - X_{iP})^2 + (Y_{iR} - Y_{iP})^2 + (Z_{iR} - Z_{iP})^2}}{n} \qquad (2)$$

X_{iR} is the recorded and X_{iP} the played back X component of position at the i^{th} point; the Y and Z terms are defined in a similar manner. *MSE* for force is defined analogously to (2). We also calculate the standard deviation to give a measure of the spread of position and force errors over the playback path.

Position Playback The results show that smaller r and larger k tend to yield lower position errors. But we cannot reduce r and increase k indefinitely as this introduces a buzzing effect. For the results of Figs. 3, a nominal constant value of k = 0.38 *N*/*mm* was used, and r was varied by steps of 0.10 *mm*. In the results of Figs. 4, a nominal constant value of r = 0.06 *mm* was used, and k was varied by steps of 0.02 *N*/*mm*. In both the plots, standard deviations are included for the case where the playback forces are included (shown in solid blue). Standard deviations are not included for the cases without the recorded forces played back (but with haptics model on, shown in dashed green) simply because the plots are too cluttered. The *MSEs* can be easily compared in the plots.

Using OpenGL, two curves were drawn, the red one representing the recorded positions and the green one showing the path traced by the PHANToM upon playback (see Fig. 5). It was observed that the two lines were close throughout the entire motion, so the position error is constant throughout the trajectory.

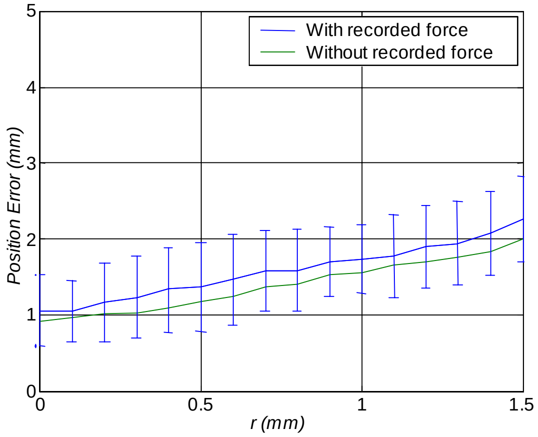

Figure 3. Position *MSE* vs. *r*, Without Finger

Force Playback. During playback the reaction forces on the PHANToM are compared with the recorded forces and the force mean square error is calculated, similar to the position *MSE* in (2); also, standard deviation is calculated and displayed as in the previous position error plots

The force error obtained is on the order of 0.3 – 0.4 N (See Figs. 6 and 7). For the result of Fig. 6, a nominal constant value of k = 0.38 *N*/*mm* was used, while in the results of Fig, 7 a nominal constant value of r = 0.06 mm was used.

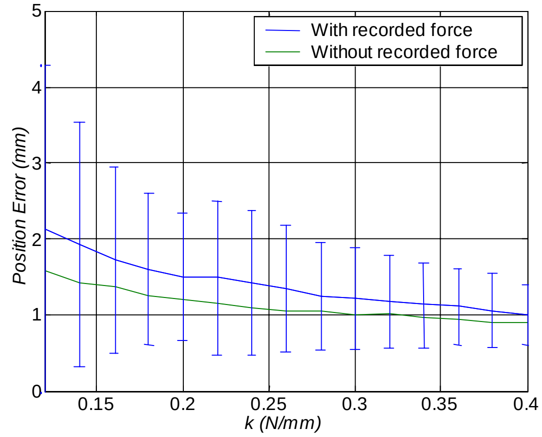

Figure 4. Position *MSE* vs. *k*, Without Finger

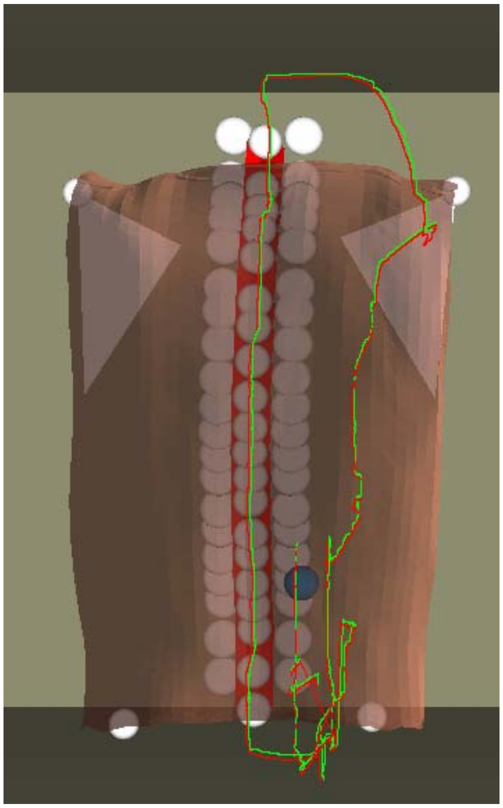

Figure 5. Playback and Recorded Paths

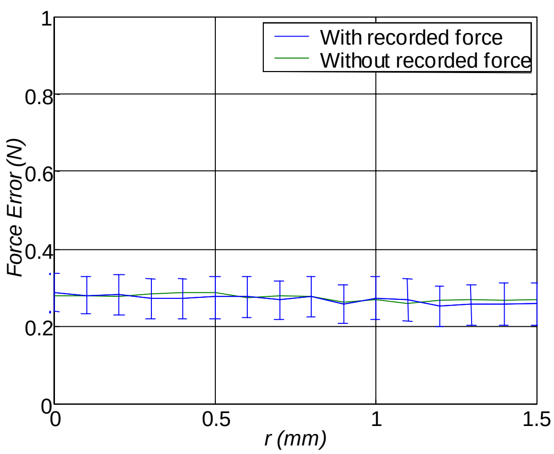

Figure 6. Force *MSE* vs. *r*, Without Finger

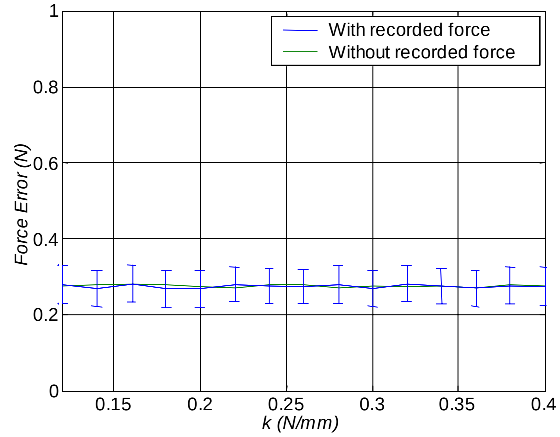

Figure 7. Force *MSE* vs. *k*, Without Finger

5. Conclusion

The position error increased with increasing *r* and decreased with increasing *k*. The position playback is faithful, observed through numerical, graphical, and subjective means. The force errors remained relatively constant, with little or no dependence on *r* and *k*.

When the system is in normal mode (not playback mode), the PHANToM motors act against the movement of human finger when an obstacle is encountered in the virtual environment. The human finger resists this force feedback to feel the modeled haptic sensations. In playback mode in our system the human finger is passive. Hence, accurate force feedback may not be obtained.

We do record the reaction forces and send them back to the PHANToM. But at the same time we send the driving force for position playback to the PHANToM, to move it through the recorded positions path. These two types of forces (position playback, haptic feedback) interact and hence the desired force feedback may not be achieved. But since the haptic forces are small, the force feedback subjectively appears to be faithful.

6. Future Work

A near-term goal in the project is to perform playback experiments with trainees to determine the potential impact of the playback feature on learning palpatory diagnosis tasks using our Virtual Haptic Back. The current article studies only the system performance regarding playback, not including any human trainees. Another future goal is to integrate two PHANToM interfaces, including playback, within the Virtual Haptic Back. Users can then use their thumb and forefinger to palpate as they do in the real world.

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