Preliminary Evaluation of a Virtual Needle Insertion Training System

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ABSTRACT

Inserting a needle to perform a biopsy requires a high haptic sensitivity. The traditional learning methods based on observation and training on real patients are questionable. In this paper, we present a preliminary evaluation of a VR trainer for needle insertion tasks. The system aims to replicate an existing physical setup while overcoming some of its limitations. Results permit to validate some design choices and suggest some UI improvements.

Keywords: Haptic perception, surgical training, user evaluation.

Index Terms: H.5: Artificial, augmented, and virtual realities—evaluation/methodology; H.5.2:User-centered design—Haptic I/O

1 INTRODUCTION

Biopsy consists of inserting a needle in the human's body to reach a target tissue, with limited real-time visual feedback. This requires having a high haptic sensitivity, including, for instance, detecting the needle penetration of an organ. Hence, clinicians need to train their haptic perception skills to master this task. Commonly, novices are trained under the supervision of a skilled clinician introducing some ethical and patient safety issues [1]. Practicing on a simulator reduces risks for patients and can improve haptic perception training. In this context, VR with haptics has been widely used in needle insertion trainers [2,3,4].

In this paper, a new needle insertion VR trainer is evaluated. VR is expected to overcome some limitations of a previously designed physical trainers [5] by offering a more controlled training environment. The aim of this research is to validate some aspects of the system user interface (UI) based on users' feedback.

2 DESIGN AND DEVELOPMENT OF THE USER INTERFACE

To simulate the biopsy needle, a needle holder was modeled, and printed using a 3D printer. It was then connected to a SensAble Phantom Omni device to allow virtual needle manipulation and haptic feedback perception. To simulate needle penetration into different layers of soft tissue, a state-of-the-art model was used [6] with different coefficients for each layer.

Beside the physical interface, a virtual environment (VE) was created. It includes a virtual needle and a rectangular object simulating a soft tissue (penetrable surface), lying on a table. The virtual needle is controlled by the physical interface. Moreover, a virtual hand holding the needle was added to increase the realism and to give spatial cues to the user. The VE was created using CHAI 3D [7]. The GEL dynamics engine was used to simulate soft tissue visual deformations during needle insertion.

3 PRELIMINARY EVALUATION STUDIES

Two user studies were conducted to evaluate the system UI.

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3.1 Participants

Twelve students and staff from a research lab at a University were recruited for the studies (10 males, 2 females, 24-38 years old, 10 right-handed). All of them reported a limited experience with haptics, VR and needle insertion.

3.2 Experimental Setup

The VE was displayed on a 37 inches monitor positioned at 45°. To compare the VR with the physical system [5], a physical setup consisting of an actual biopsy needle and a silicone gel sample (with similar compliance as the VR tissue) was used.

3.3 Study 1: Validation of the Virtual Interaction Point

A virtual hand holding a needle was used as the user's interaction point in the VE. This simulates what the user could see from a first-person perspective when manipulating the real needle. The non-animated virtual hand was attached to the virtual needle and both were controlled by the haptic device. This was compared to two interaction metaphors previously used in the literature: a virtual needle only [2] and a virtual needle tip [8]. We hypothesize that the virtual hand and needle would increase the VE realism and the perceived user's accuracy when manipulating the needle.

3.4 Study 2: Validation of the User's Viewpoint

One critical issue when designing a VE is to choose the users' viewing angle. In our system, users are not allowed to change their viewpoint. It is then important to set the correct viewing angle for performing correctly the task. For that, three viewing angles were compared: a top angle (simulating a user looking at the tissue from the top), a lateral angle (simulating a user looking at the tissue from the side) and an inclined angle (simulating a user looking at the tissue at 45 degrees). We hypothesize that the inclined viewing angle would be the best suited for this task.

3.5 Experimental Design

A within-subjects design was used for both studies. The independent variable in study 1 was the user's interaction point with three modalities: the virtual hand and needle (VHN), the virtual needle (VN), and the virtual needle tip (VNT). The independent variable in study 2 was the viewing angle with three modalities: a vertical viewing angle (the virtual camera positioned on top of the VE and a horizontal monitor: 0° condition), an inclined viewing angle (both the virtual camera and monitor positioned at 45°: 45° condition), and a horizontal viewing angle (the virtual camera positioned in front of the VE and a vertical monitor: 90° condition).

3.6 Task and Procedure

The same task was used for both studies. Subjects were asked to insert the needle inside the tissue and repeat this task for two minutes. At the beginning of study 1, they were allowed to freely manipulate the needle to become familiar with the system. For both studies, the subjects were first asked to perform the task on the physical system. Then, they were asked to repeat the same task in the VR system for each of the three experimental conditions of each study. The presentation order of the VR conditions was counterbalanced. After completing all trials, subjects ranked the system features using a questionnaire.

3.7 Data Collection and Analysis

In study 1, the questions were focused on two components: the VE realism as compared with the physical setup and the feeling of accuracy when performing the task. The questions in study 2 were focused on three components: the realism, the comfort and the accuracy. A 5-point Likert scale was used for each question (from 1 (Completely disagree) to 5 (completely agree)). Moreover, subjects were asked in study 1 to rate the usefulness of the virtual hand and asked in study 2 to classify the viewing angles according to their preference. Finally, they were asked to comment on their experience with the system after session completion. The mean scores for each condition were compared using non-parametric tests for ordinal data (Kruskal Wallis and Mann Whitney tests).

3.8 Results

In study 1, the Kruskal Wallis test showed no significant effect of the interaction point on the realism ($H_{(df=2)}$=0.12, p>0.05) and a significant effect on the feeling of accuracy ($H_{(df=2)}$=21.13, p=0.000). The Mann Whitney test with Bonferroni correction showed that the users felt more accurate (U=27, p=0.02, U=4.5, p<0.000) with the virtual hand (as compared to the VN and VNT conditions, respectively) and felt less accurate with the needle tip (U=29.5, p=0.03; Fig1). Subjects ranked the usefulness of the virtual hand high (mean= 3.91; stadard error=0.19).

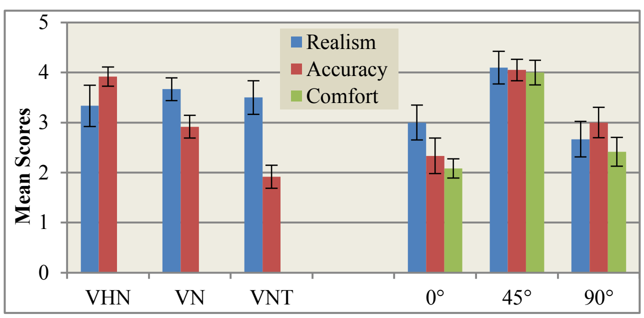

Fig1: Users' evaluation: (left) interaction points; (right) viewing angles (error bars represent the standard error)

In study 2, the Kruskal Wallis test showed a significant effect of the viewing angle on the realism ($H_{(df=2)}$=7.99, p=0.02), the comfort of use ($H_{(df=2)}$=11.25, p=0.004), and on the feeling of accuracy ($H_{(df=2)}$=19.91, p<0.000). The Mann Whitney test with Bonferroni correction showed that subjects found the environment more realistic (U=29.5, p=0.03, U=34.5, p=0.02), more comfortable (U=31.5, p=0.01, U=21, p=0.006) and that they were more accurate (U= 6.0, p<0.000, U=18.0, p=0.003) with the inclined viewing angle (as compared with 0° and 90° conditions; Fig1). No significant differences were found elsewhere (U=59, p>0.05, U=50, p>0.05, U=59, p>0.05). Finally, 91% of the subjects ranked the inclined angle as their preferred viewing angle, 66% ranked the horizontal angle as their second choice, while 75% ranked the vertical viewpoint as their last choice.

4 Discussion and Future Work

In this paper, two experimental studies were conducted to validate some aspects of the UI of our needle insertion VR trainer. The results show that, although the virtual hand increased the user's feeling of accuracy, it did not increase the overall realism of the environment. One possible explanation is that the virtual hand was non-animated and did not replicate all the users' finger movements. This may have limited the users' feeling of the virtual hand to be their own hand. Regarding the accuracy, the subjects commented that the virtual hand was useful by offering more spatial cues than the two other interaction points. This suggests that the virtual hand is useful for this task. However, to increase the realism, other paradigms, such as allowing users to see their own hand holding the virtual needle [9] should be considered.

Moreover, study 2 showed that the inclined viewing angle increased the realism, the comfort, and the feeling of accuracy. Almost all the users preferred this viewpoint. They commented that this angle of view was the closest to what they have experienced on the physical setup. However, some of them commented that they sometimes needed to change their viewpoint to ensure the needle positioning was correct. Hence, a head tracking system should be used to allow them changing freely their viewpoint by controlling the virtual camera.

These results validate some aspects of our UI and suggest some improvements for a better interaction with the system.

In the future, it will be necessary to involve experts in the evaluation studies and have their feedback. Moreover, it will be interesting to consider objective measurements such as task completion time and accuracy. One other important aspect of the system to validate is the haptic feedback model. In fact, it is necessary to show that the simulated tissue has similar haptic properties as the real tissue. Once the different UI features are validated, we need to validate the overall system as an efficient training tool for the needle insertion task.

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