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Study of Interaction Fidelity for Two Viewpoint Changing Techniques in a Virtual Biopsy Trainer

Aylen Ricca*

Amine Chellali*

Samir Otmame*

* IBISC Laboratory, University of Evry, France

ABSTRACT

Virtual Reality simulators are increasingly used for training novice surgeons. However, there is currently a lack of guidelines for achieving interaction fidelity for these systems. In this paper, we present the design of two navigation techniques for a needle insertion trainer. The two techniques were analyzed using a state-of-the-art fidelity framework to determine their levels of interaction fidelity. A user study comparing both techniques suggests that the higher fidelity technique is more suited as a navigation technique for the needle insertion virtual trainer.

Keywords: Interaction fidelity; Surgical training; User evaluation.

Index Terms: H.5 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities — Evaluation/methodology; H.5.2 [User Interfaces]: User-centered design — Haptic I/O — Evaluation/methodology;

1 INTRODUCTION

Currently, the most common method for training surgeons is the use of simulators [10]. These systems permit to practice skills in a simulated environment (VR environments, mannequins...etc.) prior to real-world exposure. The effectiveness of a VR simulator, though, is determined by the trainee's ability to transfer the skills learnt during training to the real world [5]. This introduces the concept of simulator fidelity, i.e. "the similarity between the knowledge taught in a simulator to the one used in the real world environment" [11]. While it is intuitive to think that higher fidelity will naturally increase a VR simulator training effectiveness [3], other researchers have shown that low-fidelity trainers could be sufficient [1, 4].

However, it is important to distinguish between two different aspects of simulator fidelity – display fidelity and interaction fidelity. Display fidelity is related to the realism of the simulated environment and is defined as – the objective degree of exactness with which real-world sensory stimuli are reproduced [8]. It is affected by the system's quality of the visual, auditory, and haptic feedback. It should be used to positively affect interaction fidelity.

Interaction fidelity is defined as – the objective degree of exactness with which real-world interactions can be reproduced [8]. Interaction fidelity plays a central role in the transfer of knowledge from VR trainer to the real world. It is affected by the ease of interaction and level of user control of the system [3].

In this context, McMahan [6] has proposed a theoretical framework of interaction fidelity analysis (FIFA). This framework

decomposes interaction fidelity into three main components: Biomechanical Symmetry (body movements), Control symmetry and System appropriateness (suitability of the technique). However, it has never been used to assess VR surgical simulators.

Following an iterative design process, we have previously developed a prototype of a biopsy VR simulator [7]. Biopsy is a minimally invasive surgical procedure that consists of inserting a needle into the human body to reach a target tissue (e.g. a tumor). This procedure is performed with a limited real time visual feedback to guide the manipulation of the needle. Therefore, the accuracy of this task requires high haptic and 3D spatial abilities. The evaluation of the previous prototype by novices and expert clinicians pointed out the limited navigation possibilities within the virtual environment (VE). In this paper, we present a new iteration that aims to design navigation techniques (i.e. changing user's view point) for the system with a specific focus on studying their interaction fidelity aspects using FIFA. A user study is also presented to compare these techniques.

2 DESIGN AND DEVELOPMENT OF THE VR TRAINER

For our system, two distinct navigation techniques are proposed [9]. These techniques correspond to existing metaphors usually used for navigation inside VE but which have different levels of interaction fidelity.

2.1 Head-Tracking Based Technique

This technique is based on tracking the user's head position and to update the virtual camera position in the simulator accordingly. It allows the user to change his point of view freely within the scene by simply moving his/her head, similar to what the clinician experiences when performing the real-world task.

2.2 Touch-Based Technique

This technique is inspired by the fact that clinicians use their non-dominant hand as a local reference frame when performing the needle insertion task. This is related to the asymmetrical bimanual model [2] which argues that the non-dominant hand serves as a frame of reference for tasks performed using the dominant hand. Two hand gestures are proposed, dragging to rotate the scene in the opposite direction of the movement, and pinch to zoom in/out.

2.3 Application of FIFA on the Navigation Techniques

Head-tracking (HT) technique has a higher biomechanical symmetry than touch-based (TB) since body movements involved and forces applied are those of human's real navigation. Regarding control symmetry characteristics, both techniques have a high-fidelity dimensional symmetry, allowing controlling virtual camera's position. However, while user's movement is mapped to the same movement of the virtual camera for HT technique (high transfer function symmetry level), TB navigation requires converting finger movements to a delta angle (rotations) or to a displacement (zoom) prior to updating the camera position (low-level approach). Termination symmetry in natural navigation is identically reproduced in HT, but requires taking off the finger

* {aylen.ricca, amine.chellali, samir.otmane}@ibisc.fr

from the screen for TB (lower level). Finally, TB navigation has a lower level of system appropriateness because gesture detection determines a higher latency and requires a touch input device.

As a whole, HT is classified as a high-fidelity interaction technique and TB as a moderate-fidelity interaction technique.

3 USER STUDY

To compare the two techniques performance, a user study was conducted using the newly developed prototype (Figure 1).

Fourteen naïve subjects with a limited experience with needle insertion tasks participated in this study. The study followed a within-subject design with one factor (navigation technique) with two levels: head-tracking (HT) and touch-based (TB) techniques.

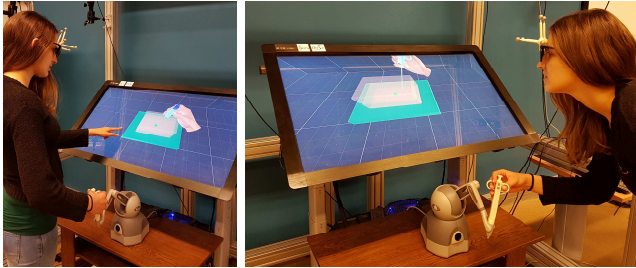


Figure 1: (left) Touch-Based and (right) Head-tracking techniques.

4 RESULTS

4.1 Objective Measures

The paired-samples t-test showed a significant main effect of the technique on the completion time ($t_{13}=2.25$, $p=0.04$). The participants performed the task faster in the HT condition. In addition, although participants were more accurate in the HT condition, the paired-samples t-test showed no significant effect of the technique on the accuracy ($t_{13}=0.56$, $p=0.58$).

For a more in depth analysis, accuracy was compared for each axis separately. One-way ANOVAs show no significant effect of axis ($F_{(2,39)}=2.38$, $p=0.10$) on the accuracy for HT condition and a significant effect of axis ($F_{(2,39)}=7.12$, $p=0.002$) on the accuracy achieved for the TB condition. The post hoc tests with Bonferroni correction show that participants were more accurate on the X-axis (lateral) and on the Z-axis (vertical) than on the Y-axis (depth) ($p=0.003$, $p=0.02$; respectively).

4.2 Subjective Evaluation

Overall, 71% of the participants preferred the Head-Tracking technique over the Touch-Based technique, and 64% of them thought that it is easiest to learn. Finally, half of them believe that they performed better with it. Although the scores were higher for HT for all the categories, the Wilcoxon non-parametric tests show no significant effect of the technique for realism and possibility to navigate/ manipulate, and only a marginal effect on ownership ($Z=-1.72$, $p=0.08$) and agency ($Z=-1.86$, $p=0.06$).

5 DISCUSSION AND CONCLUSION

Following an iterative design approach, we have designed two navigation techniques for our biopsy VR simulator. They were inspected using the FIFA framework to characterize their levels of interaction fidelity. We have used this framework for the first time here for the specific field of VR surgical simulators.

Our results suggest that the higher fidelity navigation technique permits to perform the needle insertion task significantly faster than the moderate fidelity. Not surprisingly, head-tracking technique reported to be easier to learn, and was preferred over

the touch-based technique. This can be attributed to its higher level of biomechanical symmetry.

Besides, this technique seems to generate a greater feeling of ownership and agency although the differences were not significant as compared with the moderate fidelity technique. This can be attributed to the higher control symmetry level that it has over touch-based navigation. The results show also that this technique allows the users to perform the task more accurately although no significant difference was found.

Taken together, our findings suggest that the higher fidelity technique is more suited as a navigation technique for the needle insertion virtual trainer. Indeed, in addition to being the closest in terms of interaction to what trainees should perform during the real biopsy task (high interaction fidelity), it allows them to have the best performance and the best user experience. This is an important finding that suggests that higher interaction fidelity is important to increase the performance in VR surgical simulators. However, it is important in the future to show whether this technique is also better suited for knowledge transfer to the real world task. This will further demonstrate the importance of interaction fidelity in the design of VR surgical simulators.

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