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Short Paper: Towards Interacting with Force-Sensitive Thin Deformable Virtual Objects

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Abstract

The selection of the right input devices for 3D interaction methods is important for a successful VR system. While natural direct interaction is often preferred, research has shown that indirect interaction can be beneficial. This paper focuses on an immersive simulation and training environment, in which one sub-task it is to carefully grasp and move a force-sensitive thin deformable foil without damaging it. In order to ensure transfer of training it was necessary to inform the user of the fact of gentle grasping and moving the foil. We explore the potential of three simple and light-weight interaction methods that each map interaction to a virtual hand in a distinct way. We used a standard tracked joystick with an indirect mapping, a standard finger tracking device with direct mapping based on finger position, and a novel enhanced finger tracking device, which additionally allowed pinch force input.
The results of our summative user study show that the task performance did not show a significant difference among the three interaction methods. The simple position based mapping using finger tracking was most preferred, although the enhanced finger tracking device with direct force input offered the most natural interaction mapping. Our findings show that both a direct and indirect input method have potential to interact with force-sensitive thin deformable objects, while the direct method is preferred.

Categories and Subject Descriptors (according to ACM CCS): Systems and Software [H.3.4]: Performance evaluation— Three-Dimensional Graphics and Realism [I.3.7]: Virtual Reality—

1. Introduction

3D interaction methods are a crucial element of any virtual environment (VE) and the selection of the right input devices for these methods is important for a successful VR system. This paper addresses a prerequisite to design a 3D user interface for an immersive VE for on-orbit servicing, a flexible and safe environment for planning, analysis and training of on-orbit servicing tasks. Our goal is to provide a multi-modal virtual environment that delivers a life-like simulation to train astronauts or tele-operation for EVA (extra vehicle activity) tasks. Such tasks include the removal of the protective multi-layer insulation (MLI) foil, opening and closing lock mechanisms, changing modules, taking measurements and more. Consequently, the simulation environment needs to support a wide range of object manipulations, and therefore it is necessary to select a suitable interaction method that enables this. In this paper, we concentrate on the specific sub-task of MLI removal. As the MLI is a sensitive thin deformable object, the challenge we faced was to find an appropriate interaction method that familiarizes the situation of gently grasping and moving the foil without damaging it, while still supporting all other tasks within the training simulator, e.g. does not require switching between specialized devices.

The effectiveness of training environments is established on their ability to deliver a successful “transfer of training”. For VEs that replicate real world situations, it is determined by the amount of correct transfer of cognitive and motor skills from the VE to the real world [WHK98, GH87]. In such environments, the relevant information is accessed and transferred, the greater the similarity the greater the transfer [Ham05]. For that reason, an incorrect choice of input device or interaction method in VEs can cause negative transfer or no transfer, especially for psychomotor tasks, due to the incompatibility of movements performed in the VE to those needed to perform the task in the real world. In order

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to ensure the correct transfer of training for MLI removal as a sub-task, the VE should fulfill two main requirements: inform the user of the fact that MLI removal requires gentle grasping and allow unrestricted movement of the stretched arm for moving the foil.

Various interaction devices have been developed, especially in the haptic community, that allow the training of kinesthetic movements. However, most of these devices suffer from drawbacks, such as being grounded or mounted to a surface, being heavy, large and uncomfortable (e.g. [OGTV05]). Although it may be beneficial, haptic feedback was not necessarily required for the training of this task. We seek to provide an interaction method that is easy to use and easy to integrate into immersive VEs, as well as allows intuitive simulation of physical interaction between human and the environment without restricting the movement within the VE. We propose and explore the potential and usefulness of three forms of interaction mappings using a light-weight finger-tracking device, as well as a tracked joystick.

2. Interaction Mappings

Two main approaches for designing 3D interfaces have been proposed in research. One refers to the "magic" or non-isomorphic interfaces, and the other to "natural" or isomorphic interfaces [BKLP05]. Magic interfaces have been suggested when the tasks require productivity and efficiency. However, if the replication of the physical world is an important aspect, then natural interaction interfaces are used. One of the common methods for interaction with a virtual object is the "virtual hand" metaphor, where the user is provided with a 3D cursor, shaped like a human hand, and the position and orientation of which is controlled by a tracker attached to the user's hand. We implemented a simple rigid body based model for the virtual hand, and a soft body model for simulating the MLI foil. Applying a subtle force to the rigid bodies was required to create enough friction to allow slightly pulling the foil to keep it stretched while moving it without losing grip. This simulation was needed to familiarize the user with the situation of gently grasping of the MLI. We used an extended finger tracking device with a pinch force sensor. It is light-weight and allows measuring the intensity of pinch force. Two different mappings to the virtual hand using this device were implemented. One is mapping the pinch force directly to the grasping force of the virtual hand. The other uses the finger distance to derive the force.

On the other hand, researchers have suggested that non-isomorphic mappings which included controller or joystick like devices can also be useful and intuitive [BKLP05]. For example, in a related comparative study, Moehring et al. [MF11] compared finger-based direct interaction to indirect controller-based ray interaction in a car interior evaluation scenario. Their results showed that finger-based direct interaction was generally preferred over indirect controller-based ray interaction. Though, controller-based interaction was often faster and more robust. In our training application, a tracked joystick controller could also allow the simulation of grasping force by mapping the analog value of the joystick axis, as well as the required arm movement when moving the MLI. Therefore, we further designed an interaction method with an indirect mapping using a tracked joystick in addition to our direct mappings using a finger tracking device. Furthermore, the use of a tracked joystick allowed us to weigh the direct interaction techniques using the finger tracking device against an indirect interaction technique.

Direct Force Input: We used a finger tracking device that was equipped with electrodes around the finger tips measuring the skin resistance between finger and thumb. The intensity of the contact was directly mapped to the force that was applied to the virtual fingers when grasping a thin object, see Figure 1(a). It delivers analog values in the range of 0 to 1, where 0 is no pinch at all and 1 is the maximum pinch that can be measured. The sensitivity of measuring the pressure of a pinch heavily depended on the skin type and moisture. Therefore, the resulting force was calibrated for each user in our current setup.

Finger Distance: The finger tracking device supplied us with the position and orientation for the back of the hand and for all five finger-tips. Force control was mapped linearly to the distance d between the finger and the thumb, as shown in Figure 1(b). When the user's hand was still open for about 3cm, the virtual one was already closed with the finger and thumb touching each other. Moving the finger closer than 3cm would apply a force to the virtual hand. We mapped the shortest Euclidian distance between one finger and the thumb to the applied normalized force.

Tracked Joystick: For the indirect interaction technique we used the standard interaction device of our VR system, a Flystick2. It is a tracked 6DOF target that has 6 buttons and an analog joystick along the x- and y-axis. We linearly mapped the analog value of the joystick y-axis (up-down) to opening and closing of the virtual hand. Pushing it up would open the hand, and pulling it down would close the hand. In it's neutral position, the fingers were just before closed, so that the user had to pull down the joystick to apply the desired force. While holding the Flystick2 in the user's hand, the joystick was operated with the thumb, as shown in Figure 1(c).

3. User Study

We conducted a summative user study evaluating the usefulness and potential of the distinct interaction methods. We studied the effect on the interaction task by measuring the task performance and by collecting the subjective user experience and preferences.

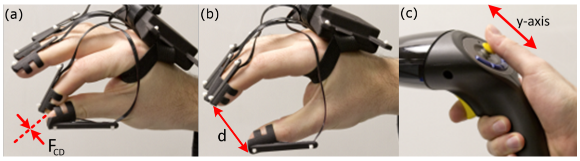

Figure 1: *The grasping force of the virtual fingers was mapped directly through pinch force (a), based on the distance between tracked fingers (b), and indirectly through a tracked joystick (c).*

3.1. Participants

Nineteen people participated in the study, all with engineering or computer science background. The age varied between 20 to 50 years. Four participants were female. All were right handed. Thirteen had little, two had medium experience and four had high level of VR experience. Likewise, two of the participants had never used any VR interaction devices before, four had used them rarely, seven used them often and four regularly.

3.2. Task and Environment Design

In our on-orbit servicing simulation, all electronic parts and the structure of a satellite mockup were covered by the MLI. A part of the foil was placed loosely 6cm above a cabinet of modules that had to be serviced. The interactive part of the MLI was 70x52cm wide and about 1mm thick. We modeled the foil as a spring-damper system of 10x10 nodes with a total mass of 100g and a linear stiffness of 0.7. The virtual hand was simulated as a set of rigid bodies resembling the palm and five finger segments at the finger tips per hand. The task was to apply a subtle force to the rigid bodies to create enough friction to allow slightly pulling the foil to keep it stretched while moving it in a wide arc of approximately 1m without losing grip. The only condition was to keep the normalized force at a value between 0.4 and 0.75 (displayed for user's reference in an overlay text on the screen). Applying too little force would cause the foil to slip out of the virtual hand, while applying a force above the allowed range would cause the intersections between foil and virtual hand and thus the foil to tear. Apart from MLI removal, other tasks were not evaluated in the trails for this study.

3.3. Dependent Measures

We measured the total time that a user took to perform a task, as well as the resulting force that was applied to the virtual hand while using the different interaction mappings. This also provided us with an insight into how a user controls the force that was applied on the MLI foil. Another metric was the successfulness of the task in form of actions such as tearing the MLI, MLI slipping out the hand and successful removal of MLI. The subjective feedback was collected in form of a user experience and preference questionnaire.

3.4. Procedure

The participants, were asked to move the virtual hand to the right side of the MLI, and then gently grasp it and pull it carefully over to the left side. Each participant performed three trials of each interaction devices, Flystick2 (FS), finger tracking with distance measurement (FT) and direct force input (FT-F) respectively. We used a repeated measures design and in order to counterbalance the learning effects, we changed the order of devices that were given to the participants. After a short introduction, the participants were allowed to practice and familiarize themselves with the interaction techniques and the task before starting the trials. After the end of three trials for each interaction method, the subjects were provided with a questionnaire.

The study was conducted in front of a 1.9x3.5m Powerwall, which is an active stereo 3-pipe rear-projection system with a total resolution of 2550x1400 pixels. Tracking was provided by a six-camera optical tracking system by ART GmbH. The test scenario was implemented using the VR-OOS software framework [WPG11], which provided real-time rigid and soft body physics simulation based on the Bullet physics engine and interfaces to a wide range of immersive VR systems.

4. Results and Discussion

While performing the statistical analysis, we checked whether the required assumptions of parametric data have been met. To achieve a balanced dataset for the purpose of analysis of variance and non-parametric two sample test we removed five trials which had errors in recording the data.

Task Performance: We performed a repeated measures ANOVA on the total time taken and total grasp time for the three interaction methods. The total time taken and the total grasp time were not significantly different from each other, where $p=0.316$ and $p=0.347$ respectively, between the interaction methods. Furthermore, we performed a Chi-Square analysis on the success rate of the attempts, which shows that the proportion of successful attempts to the unsuccessful attempts in the three interaction methods were not significantly different, test statistic $\chi^2(2)=1.297$, $p=0.466$. Thus, there was no difference in terms of task performance among the indirect and direct interaction methods. These results deviate from results observed in previous similar studies [MF11], however this could be due to the nature of task that was being performed in our study, which placed high demands on users for accuracy.

Questionnaire Figure 2 shows the results from the questionnaire. We performed a non-parametric Wilcoxon signed-rank test on the ease of controlling the force, intuitiveness

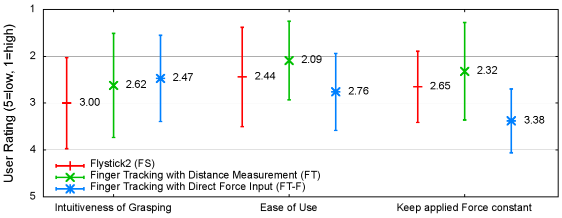

Figure 2: *User ratings for intuitiveness of grasping (five point scale, with 1=very intuitive, 5=not intuitive), ease of use (1=very easy, 5=difficult) and ease of keeping force constant (1=very easy, 5=difficult) of the three interaction methods.*

for grasping the MLI and ease of use for the three different interaction methods respectively. There was no significant difference observed in ratings of intuitiveness of the interaction method for grasping the MLI, where FT vs. FS p=0.285, FT-F vs. FS p=0.213 and FT-F vs. FT p=0.552. Performing a non-parametric Wilcoxon signed-rank test on the ease of use showed that the overall ease of using FT (Mdn=2.0) was significantly higher than the ease of using FT-F (Mdn=2.5), z=-2.294, p=0.022, r=-0.55. The ease of using the FT was similar to that of using FS, however it is important to note that the ease of using the FT-F was lower than that of using FS and also FT. Furthermore, the results also show that the ease of keeping the force constant was significantly higher with FT (Mdn=2.0) than FT-F (Mdn=3.5), z=-2.802, p=0.005, r=-0.67. The ease of keeping the force constant was significantly higher using FS (Mdn=2.0) than using the FT-F method (Mdn=3.5), z=-2.045, p=0.016, r=-0.49. It is also important to note the effect size of the differences that were observed here. The difference between FS and FT-F is smaller than the effect size between FT and FT-F.

FT was the most preferred method for the task, followed by FS and then FT-F. The results from task performance and the questionnaire show that FT weighs similar to that of FS. However, the higher user preference shows the potential of the direct method for the task. Hence, for the purpose of this application, a direct interaction method is appropriate. An observation that deviated from our expectation was a low performance and user rating for FT-F, even though the nature of the method was closer to the realistic way of interaction compared to FT. One of the reasons for this deviation could be explained by the observation related to applying the force. Participants stated, it was difficult to keep the applied force constant using this method. In our current implementation the range of detected pinch force was very small. This made the input device very sensitive to pinches.

5. Conclusion and Future Work

The purpose of this study was to explore the potential and benefits of direct and indirect interaction methods for the specific task of grasping and manipulating a thin force-sensitive deformable virtual object within an immersive VE. The challenge was to find an appropriate interaction method that trains the user about the fact of gently grasping and moving it without damaging it, while still supporting all other object interactions required in the training simulator. Our results showed that, in terms of task performance, the direct interaction methods using finger tracking performed equally compared to the indirect interaction method using the tracked joystick. From the subjective user feedback, we found that both, the indirect and direct interaction methods, were equally intuitive. The ease of using the finger tracking with distance-based force input weighed similar to the tracked joystick. Keeping the applied force constant was easier with the joystick and direct interaction method with distance-based force input, These observations suggest the suitability of finger tracking as a direct interaction method for the task. Even though, the pinch force method was much closer to the natural way of interacting compared to the other two methods, it had the lowest user preference. As noted in the questionnaire and discussions with the users, we believe this is due to the small range of the pinch force available. In our future work, we plan to improve the robustness of the direct force input device by scaling and filtering the sensor output values and implementing a user-based calibration method.

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