Comparative Evaluation of User Performance for Modeling Tasks in Non-immersive and Immersive Virtual Environments

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Abstract

This work deals with modeling in immersive virtual environments. We present MuscleAssemblyLab (MAL), a tool to create musculo-skeletal layers for virtual humanoids. With modular interaction metaphors it supports various input- and output-devices ranging from classical desktop systems to virtual reality hardware. This enabled us to conduct a comparative user study between non-immersive and immersive virtual environments in order to study user performance. As a result of our study, we could show that modeling in immersive virtual environments is significantly faster without loss of precision. Further observations led to enhancements of our interaction techniques used within MAL.

1. Introduction

Even nowadays, modeling is often conceived as a complicated task which should be done by trained experts. In certain applications virtual reality (VR) can be one of the most intuitive human-computer interfaces by providing multi-modal interaction and feedback. Because modeling relies heavily on interaction, our goal is to show that by utilizing VR modeling can be improved. The modeling tool that we have developed can be used with desktop systems as well as within immersive virtual environments (VE), which allowed us to perform a comparative test between these platforms. The paper is structured as follows. First we present related work about immersive modeling and modeling-based evaluation. Then we continue by describing our modeling tool and the conducted experiments including results and a discussion.

2. Related Work

In this section we give a brief overview of existing immersive modeling applications and of previous experiments focusing on modeling or related interaction tasks.

One of the first tools, 3dm was developed by Butterworth et al. [4]. It utilizes a head-mounted display and electromagnetic tracking devices to create an immersive setup. Deering used a stereoscopic desktop (crt-monitor combined with tracked shutter glasses) for HoloSketch [5]. A similar hardware-setup was also used by Turner et al. for their character modeling toolkit LEMAN [14]. Some other approaches are based on the Responsive Workbench, like Virtual Clay Modeling from Krause and Lüddemann and Free-Drawer from Wesche and Seidel [8, 15]. All these immersive VE consist of 6-DOF input devices and stereoscopic 3D visualization to provide an intuitive and natural approach for direct manipulation of virtual objects as opposed to classical 2D-input/output desktop systems. Compared to today’s mainstream 3D-tools, the usability appears to be better. However, because of expensive and limited immersive hardware and imprecise tracking, most of the immersive modeling applications were not adopted as commercial solutions or established into more common use.

Besides modeling tools which explore immersive manipulation approaches, several related user studies have been conducted. The importance of user studies has been discussed exhaustively in scientific visualization, virtual reality and related research areas [7, 3]. Mine et al. present...
body-referenced interaction methods (based on proprioception) [10]. Through succeeding experiments the effectivity of those methods was evaluated. In one task a virtual object had to be moved by the users hand. Comparing different static and dynamic offsets revealed that closer and fixed distances yield better results. These insights were confirmed by Palijic et al. [11]. They also made an interesting observation: novices and intermediate users tend to manipulate objects from fixed positions, instead of maintaining short distances between user and object. Also within this context, manipulating at remote distances (beyond arm reach) has been the focus of an evaluation by Bowman et al. [2].

3. MuscleAssemblyLab

The modeling application MuscleAssemblyLab which is used in this study has been developed in order to create musculo-skeletal models of virtual humanoids. Besides the main purpose to attach muscles to a graphical representation of a skeleton (figure 2), it is possible to manipulate the kinematics of the articulated figure. The musculo-skeletal model is later on used to drive an advanced multi-layered skin deformation algorithm. The modeling application has been designed for interactive alteration of simulation parameters at non-immersive desktop PCs, as well as in immersive VEs such as a HoloBench™ or a CAVE™ (for an example see figure 1). The user can easily modify the musculo-skeletal model in place and gets direct visual feedback.

3.1. Architecture

MAL is implemented within ViSTA, a cross-platform, multimodal VR-toolkit under development at RWTH Aachen University [1]. Furthermore the modeling-data is maintained by the ViSTA module VRZula¹, which contains general data structures and algorithms for virtual humanoids, including kinematics, biomechanical-based muscle simulation and advanced visualization techniques. The interrelation is illustrated in figure 2.

We differentiate between an interaction and a behavior component. This distinction within the user interface is based upon a design model proposed by Tranriverdi et al. [13]. The interaction component receives updates from input devices via the EventObserver, which are processed by PickHandler and LUA-scripts. The behavior component contains a collection of Operations (i.e., create new, select, delete, move or modify muscle). Those operations are called from the interaction component after passing through theStateMachine. Because of this separation, the input device or interaction metaphor for an operation can easily be changed.

3.2. Interaction metaphors

During the development MAL underwent several iterative small-scale user-centered design cycles which resulted in the following interaction metaphors:

**selection:** checking for intersections between virtual beam attached to an input device (mouse at desktop, wand in VE) and objects in the scene; used to select menu items, skeleton and muscle geometry

**movement:** selecting a bone geometry of the virtual skeleton automatically changes into a movement mode as long as a button of the assigned input device is hold down; moving or rotating the device changes the orientation of the selected bone and transforms its children accordingly (forward kinematics)

**navigation:** changing the viewpoint solved by a headtracking-device within immersive VEs and improvised on non-immersive systems through indirect interaction.

**manipulation:** when a muscle is selected, the system switches into an edit-mode and object-handles are shown at the endpoints of the muscle; by moving an endpoint along the skeleton a muscle gets stretched or squeezed and positioned on the skeleton (cp. figure 2).

4. Experiment

The modeling tool MAL was used to perform a user study. The goal was to compare the user performance between different environments (non-immersive vs. immersive). Two hypotheses were stated: (1) In immersive environments modeling tasks can be performed faster and (2) In immersive environments the results are more precise.

The hypotheses were based on the fact, that an immersive VE permits natural mapping for interactions through 6-DOF devices and intuitive exploration of the resulting
model, compared to indirect and constrained interactions and exploration on a desktop system. We assumed that additional DOF would speed up the overall task completion time and that interactive exploration might improve the accuracy.

4.1. Design

The experiment was divided into two similar parts which only differed in the used platform. All test persons (the average age was 27.09±3.23 years, ranging from 22 to 36 years) have participated in both sessions: one with a desktop system and another in a CA VE-like environment. The time between both sessions was chosen as two weeks in order to minimize learning effects. Both sessions were planned as a usability test [12]. The time to accomplish the given task was taken for each test person to measure their performance. The precision of the resulting models have been calculated as the sum of the euclidean distances to a reference model. We used a specialized questionnaire to gain insight into psychological factors, containing items from an established method by Witmer et al. to measure presence [16] and items from IsoMetrics, a questionnaire used for software-ergonomics [6]. To rule out problems with perception of depth we used a test for 3D vision [9].

4.2. Test Execution and Task Description

The subjects were first given a verbal introduction into the use of MAL and were invited to explore the user interface at will. After they felt comfortable with the environment they were asked to perform several training exercises, which involved usage of all interaction metaphors described in section 3.2.

After this training the subjects were assigned a modeling task. In this task the user had to attach five muscles to the right upper arm of the skeleton and position the insertion and the origin point of the muscle according to anatomical reference pictures. These pictures were visualized as a part of the virtual environment. The reference images were supplied because anatomical knowledge was not a requirement in the user profile. The time needed to complete the modeling task was measured. Following the modeling session the test persons had to complete the presence and the IsoMetrics questionnaire (cp. section 4.1).

5. Results

Each of the 23 subjects accomplished the assigned task and completed the post-test questionnaires. Three files containing the results of the modeling task were corrupted and could not be used for the analysis of the precision metrics.

5.1. Performance Metrics

The measured time was analyzed with a paired t-test. The time to complete the task in the CA VE-like environment was found significantly lower compared to the time needed with a desktop (p < 0.001, T = 5.054, df = 22). The normal distribution of the time measures was checked by the Kolmogorov-Smirnov test. The mean time for the modeling task was 10.43 minutes (S.D. 2.92) in the immersive VE, compared to 14.30 minutes (S.D. 4.77) at the desktop PC. A boxplot of the results is presented in figure 3.

The analysis of the precision of the resulting model — which is given by the euclidean distance of the model to a reference model — did not reveal a significant statistical difference in the mean values. The data measured suggest that there is a slight improvement from 0.357±0.193 meters (i.e. 3.5 cm per muscle) using the desktop towards 0.296±0.164 meters (i.e. 3.0 cm per muscle) in the CA VE-like environment (cp. figure 3).

5.2. Observations

Even though the users were encouraged to move freely inside the CA VE-like environment during the tutorial and the subsequent modeling task, many stayed fixed in one position and did not move closer towards the skeleton. This might explain why there was no improvement in precision as the input device was often pointed to the target location from a distance of more than 50 cm.

5.3. Questionnaires

The questionnaires show that the majority of participants prefer an immersive VE to a desktop system (cp. table 1). Compared to the desktop the users had no problems with initial orientation in the virtual world and with interaction devices (i.e., head and wand opposed to keyboard and
mouse) in the immersive VE. The overall satisfaction with the created model was higher in the immersive VE, and the assigned task was judged less exhaustive.

6. Discussion

The analysis of the performance metrics led to the acceptance of the first hypotheses proposed in the beginning of section 4. The second hypothesis could not be verified. The results show that time for task completion can be optimized even though the precision does not change and does not get worse, if modeling tasks are performed within immersive virtual environments.

As already described in section 5.2 modeling distance is an important issue. Precision of resulting models could be enhanced if users would be enforced to step closer to the target area, thus reducing the manipulation distance.

The personal satisfaction with the own work was judged by all users fundamentally higher in immersive VEs. Because the results of the precision metrics show only a slight amelioration, this contentment could be traced back to the fact that interactive, immersive exploration of the created model itself leads to a higher satisfaction.

7. Conclusions

The performed user study implies that modeling tasks can be performed faster in immersive VEs without loss of precision. Furthermore the study has shown that even users without a strong virtual reality background can achieve good modeling results in immersive virtual environments.

Refinement of the existing interaction metaphors and introduction of new ones could improve the modeling tasks even more. The selection metaphor should be changed for easier application within spatial densely clustered regions. This could be solved by two-handed interaction. Also to decrease the distance between a user and the manipulated object, we have implemented a virtual beam as manipulation metaphor which is dynamically shortened to a certain length when entering a modeling mode. In order to be able to pick and manipulate objects in the virtual world the user is forced to approach the object of interest. The beam is resized to a longer range after returning back to the selection or navigation modes.

In future studies we will investigate on optimization and user acceptance of such interaction techniques.

References