3-DOF vs. 6-DOF – Playful Evaluation of Complex Haptic Interactions

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***Abstract*—We present a haptic workspace that allows high fidelity two-handed multi-user interactions in scenarios containing a large number of dynamically simulated rigid objects and a polygon count that is only limited by the capabilities of the graphics card. Based in this workspace we present a novel multiplayer game that supports qualitative as well as quantitative evaluation of different haptic devices in demanding haptic interaction tasks.**

I. Introduction

Haptics is an essential and emerging technology and it already helps to improve human-computer as well as, in multi-user scenarios, human-human interactions in many fields of computer science like tele-operations in industrial and medical scenarios or virtual prototyping tasks in the automotive and aircraft industry.

Traditionally, haptic devices were bulky, expensive and required technical expertise for installation and handling. However, in the last years technical innovations and visionary investments, especially by the game industry, made haptic devices affordable and usable also for the consumer market. There, in addition to an enhanced immersion in computer games, the sense of touch could be an essential decision criterion for selecting products in online shops. Moreover, the sense of touch could improve the quality of skill or job training.

When providing force feedback in consumer electronics, cost is often still a limiting factor. The cost of haptic devices depends mainly on the number of actuators. Thus, the low cost haptic devices for the mass market afford only 3-DOF. However, when we interact with the real world, for example we eat with a fork and a knife, we grasp objects and get kinesthetic feedback by the interaction between these objects and their environment. This kind of interaction includes beside the 3-DOF force rendering also torques and thus requires much more expensive 6-DOF haptic devices.

This raises the question if the enhanced 6-DOF experience is worth the additional cost for the devices. Surprisingly, there is not much work on the comparison of haptic devices with different degrees of freedom. [1] presented a study about the role of torque feedback in purely haptic perception of object location in virtual environments. Research concentrated on analyzing devices with asymmetric numbers of sensors and actuators. E.g. [2] found out that for simple tasks like drawing or tracing, the performance with 3-DOF force and additional 3-DOF of positioning can approximate the performance of full force and torque feedback.

Intuitively, it seems to be obvious that full 6-DOF should be much better than 3-DOF. However, we are not only interested in a qualitative analysis, but we also present quantitative strategies to assess the advantages of full 6-DOF force and torque rendering objectively. This helps to legitimate higher costs for more expensive haptic devices, but hopefully encourages manufacturers to spend more efforts in the development of cheaper 6-DOF haptic devices.

Therefore, we have implemented a haptic workspace that allows high-fidelity 6-DOF feedback in scenarios containing a large number of dynamically simulated rigid objects. Moreover, it supports different haptic devices and two-handed multi-user interactions.

Based on this workspace we have developed a haptic multiplayer game that requires from the players complex two-handed interactions simultaneously in the same environment. Besides a user survey, we included several mechanisms to track the quality of the users actions in the game for a quantitative and qualitative analysis.

II. The Haptic Workspace

The main challenge when doing haptic rendering is the extremely high frequency that is required: While the temporal resolution of the human eye is limited to approximately 30 Hz, the bandwidth of the human tactile system is about 1000 Hz. In most haptic scenarios, the computational bottleneck remains the collision detection, whereas the force computation can be done relatively fast.

Thus, the heart of our haptic workspace is our new geometric data structure, called *Inner Sphere Trees (ISTs)*, that not only allows us to detect collisions between pairs of massive objects at haptic rates, but also enables us to define a novel type of contact information that guarantees *stable* forces and torques [3].

The main idea of the ISTs is that we do not build an (outer) hierarchy based on the polygons on the boundary of an object, like most other BVHs do, but we fill the interior of the model with a set of *non-overlapping* spheres that cover the object's volume densely. This enables us to define a novel extent of intersection, the *penetration volume*. The penetration volume corresponds to the amount of water being displaced by the overlapping parts of the objects and, thus, leads to a physically motivated and *continuous* penalty force.

Our collision detection scheme together with a novel penalty force approach that is based on the penetration volume, enable us to treat physically based simulation and haptic rendering in a common way. The only difference between dynamic objects and user-controlled objects is, that the forces for the latter are rendered to the haptic device instead of using them for the simulation. For further information we refer the interested reader to [4].

For visual output we use an open source scenegraph[1] that supports shading and multi-monitor output. Even if the ISTs are very fast, it is not possible to guarantee constant time intervals for the collision detection. Therefore, we extended the algorithm with a time critical approach and included multithreading support.

[1] OpenSG, www.opensg.org

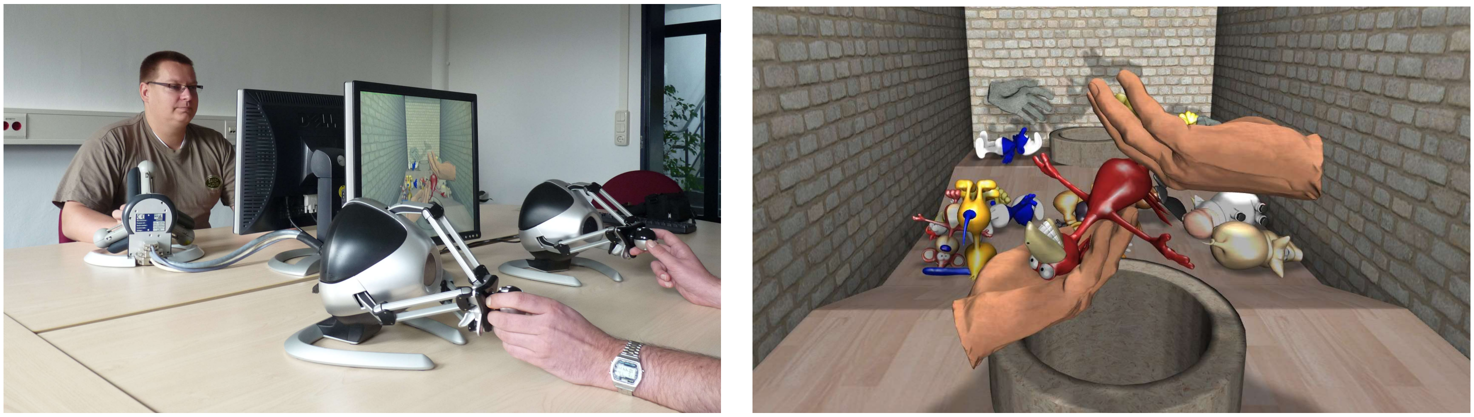

Fig. 1: *The two-player set up with four haptic devices for our user study (Left). The playing field of our haptic game (Right).*

III. The Haptic Game

Based on our haptic workspace we have implemented a simple two-player haptic game. The players sit face to face at a table with two monitors in between. Each player handles the two haptic devices on his side, one for each hand. In order to evaluate the differences between 3- and 6-DOF interactions, one of the players uses two 3-DOF devices[2], whereas his opponent operates two 6-DOF devices[3]. After finishing a round, the players swap seats (See Figure 1).

The playing field is a room with a set of ten complex objects with different shapes lying on the ground. Moreover, each player has a virtual box placed in front of him. Each player controls two rigid hand models with his haptic devices. The goal of the game is to pick up the objects and place them in their own box. The game is over when all objects are placed in the boxes or if time is up (See Figure 1).

The task is closely related to typical tasks that arise in tele-operation scenarios or virtual prototyping environments and, thus, allows conclusions of practical relevance.

For the evaluation, we record the forces and torques acting on the user-controlled hands and additionally we track the covered distances. These values allow to make conclusions about the efficiency of the haptic interaction. Moreover, we make a survey where we ask the users about the quality of the feedback and their preferences with respect to 3-DOF vs. 6-DOF.

The game environment was chosen to ensure that, due to the situation of competition, the users are highly concentrated on the challenge and not on the potentially unknown and fascinating devices. Due to the change of seats and thus the haptic devices, we are able to test a large amount of subjects in a relatively small time interval, and moreover we can keep the learning phase relatively short. Additionally, we get information about advantages or disadvantages when starting with the 3-DOF and ending with the 6-DOF device or vice-versa.

IV. Conclusions and Future Work

We presented a new multi-user haptic workspace with support for a large number of haptic devices and a likewise number of dynamic objects with a high polygon count. Based on our workspace we implemented a haptic multi-player game with complex haptic interactions that we use for a quantitative and qualitative analysis of haptic devices with respect to their number of sensors and actuators.

The user evaluation is currently under way; preliminary results show that 6-DOF devices outperform 3-DOF devices by an order of magnitude, both in user perception and in objective data analysis.

However, there are still some challenges left for the future: Further studies are necessary to find the best trade-off between cost and performance regarding two-handed complex haptic interactions. This could include asymmetric set-ups of the haptic devices, e.g. 6-DOF for the dominant hand and cheaper 3-DOF for the other hand.

Finally, there are also some challenging extensions for our haptic workspace, e.g. it would be nice to extend our approach also to deformable objects or to include networking functionality in order to support tele-operations.

[2] Novint Falcon, www.novint.com

[3] Haption Virtuose 6D Desktop, www.haption.com

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