Haptic Illusions

Leo Biegert
6biegert@informatik.uni-hamburg.de

Daniel Patanin
7patanin@informatik.uni-hamburg.de

Lars Lamberti
5lambert@informatik.uni-hamburg.de

Department of Informatics, Human Computer Interaction
University of Hamburg
Hamburg, Germany

ABSTRACT
In this project we examine the effects of visual perception measured against the sensation of haptic feedback in virtual reality (VR). Our main goal is to check for thresholds at which a user will not be able to differentiate between the feeling of a real-world object and their deformed representation in VR. For this we have set up an environment in the real world that was then rebuild virtually and put under effect of certain factors. Users were then tasked to feel real-world objects while seeing different representations of the same objects in VR and provide answers to whether those objects were deformed or not. In the end this provides us with psychometric data on how much we can distort the virtual image without the user noticing. Unfortunately, no conclusive data could be obtained due to technical difficulties.

Author Keywords
Virtual reality, 3D interaction, Visuo-Haptics, Psychometrics

INTRODUCTION
The main idea behind our investigation is to identify how much the visual perception weighs over the sensation of touch. How much can a virtual representation of a real world object be morphed so that the human brain will not be able to tell whether what it sees "is real" as opposed to the actual physical object giving direct feedback through a, in comparison, minor sense. For example, will the brain be able to process whether an edge is actually bent or whether this information is just made up by the visual sense? This idea was based off studies regarding visuo-haptic illusions and the possibility of conveying kinesthetic feedback which we will see in the upcoming section.

Originally, methods build around motion sensoring in combination with a standard VR approach (Head-Mounted Display) were planned but had to be replaced by more rudimentary technologies, namely a virtual representation of a common human hand in combination with a simple tracker strapped to the participants' physical hand, for the sake of complexity and timeliness. In addition, a table with two fixed, identical boxes was set up, both of which would then be virtually deformed at random as to provide some ambiguity and to counter a bias by simply knowing the shape of the physical boxes beforehand. The participant was able to see the physical setup beforehand, also virtual redirection to the rebuilt objects was not implemented unfortunately. This would have had a much better impact on the actual illusion, as clipping, e.g. the virtual hands moving through theoretically solid objects would have not been visible.

The final results were diminished by the fact, that due to communicative problems as well as unforeseen technical issues the gathered data was far from as meaningful as expected. Its easy to comprehend that without virtual redirection of the hand the range in which a deformation would not be obviously spotted is very minimal. Also the working environment was rather unstable, a fact that further underlines the difficulty of realising a mixed reality project.

RELATED WORK
We started looking at various approaches trying to enhance VR-experiences through haptic feedback. Generally, methods of providing such feedback can be differentiated by whether they are active or passive. The conventional approach is to use passive props to represent virtual objects and provide haptic feedback for them. This is viable for smaller scenes, but since props only can be used for virtual objects with the same dimensions, this quickly becomes unfeasible when dealing with increasing amounts of virtual objects. Active approaches instead try to emulate varying virtual forms with only one single physical object. Not only does this decrease the amount of props needed, but depending on implementation it also allows for dynamic feedback which changes while the user touches it.

The approach by Abtahi et al. [1] employs a device named tactile display, consisting of an array of extendable sqared bolts, adding up to a display. This method enables simulation of a wide range of surface geographies, allowing to represent many different objects in the virtual space with just one prop. A noticeable drawback of this compared to conventional props is the requirement of specialized hardware, which adds risk factors as well as financial demands. Additionally, the surface texture always resembles an array of rectangles, in case of the proposed shape display with noticeable holes in between, whereas a conventional prop can be selected for its surface detail and/or texture. This though is addressed by the authors through mapping virtual objects to the shape display at a higher resolution than shown visually, effectively "zooming in" the object.

A different approach found was aimed at dynamic haptic feedback, being such that it responds to and enhances the perception of the movement of the user. Methods for this are proposed by Rietzler et al. [3]. In this case, these Methods rely less on tactile feedback, being perceived when an external object touches the users skin, and more on kinesthetic feedback, being the self-perception of the position and movement of the users limbs. To increase the perception of effort when pushing a virtual object, the authors did not rely on any tactile feedback, but instead implemented a software solution that scales the rate of the users hand movement down depending on how much resistance the virtual objects should pose that the user pushes in this moment. Rietzler et al. have shown that this substitution of actual resistance with the increasing movement effort resulting from the above solution does provide the user with a similar impression of a resisting virtual object.

The study that we ultimately ended up reproducing parts of was originally conducted by Kohli et al. [2] and aimed to enhance haptic feedback for a VR user by redirection. This technique is already finding application in other areas of VR (redirected walking studies by Lucie Kruse), and consists of warping the virtual space so that the user has more possibilities to act in the virtual world than his real-world constraints (e.g. room size, or in our case prop dimensions) would allow. This is possible through the dominance of the visual sense over the others (proprioception and tactile sensation for the mentioned examples, respectively) the The authors of [2] set up various virtual objects the user was to interact with, and warped the virtual world such that the user was exploring e.g. a box with his fingertip in reality, yet in VR the object had a totally different form (which his virtual hand also followed).

IDEA

Inspired by the "zooming in"- technique from Abtahi et al. [1] and ultimately Kohli et al. [2], our intention was to reproduce and combine the two approaches. The user was to explore a physical prop, of which the virtual correspondent was not a "zoomed in" object, but instead a deformed one, all the while having the movements of his hand accelerated and therefore his reach extended to the "far-away" object. We were initially aiming to investigate the interplay between the two illusions, but had to completely put off the implementation of the latter due to technical limitations. The vision of the haptic illusion was meant to be more extreme and containing parts of redirecting touch techniques. Since we ended up discarding the long arms illusion due to technical issues and redirecting touch techniques because of miscommunication and time, we changed our attention to a minimalistic study of the thresholds by which a participant could not tell the difference between two points with haptic feedback, whilst one corresponds accurately to a real object and the other one is slightly deformed but only with the biggest deformation amount the offset could be visible.

EQUIPMENT AND SOFTWARE

For the physical devices needed to realize this project we used a HTC Vice Pro as Head-Mounted Display with a HTC Vive tracker for the mapping of the participants hand. Originally this was designed to be managed by a Leap Motion IR hand tracking device, but since the tracking accuracy of the Leap

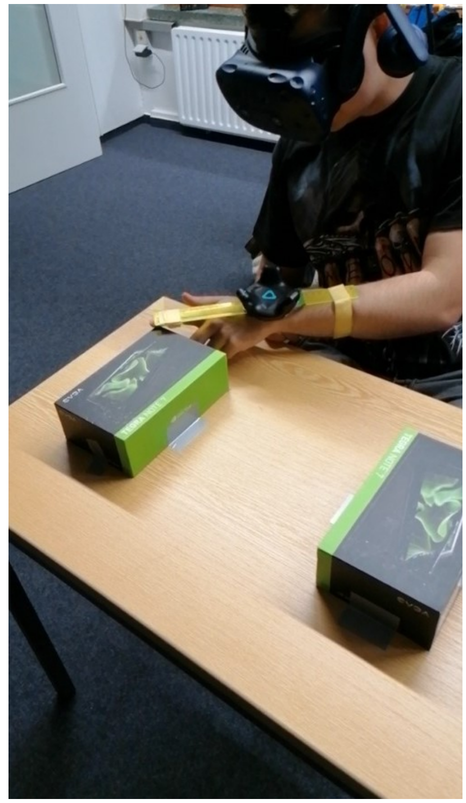


Figure 1: The physical setup of the project. A participant wearing the HMD with the tracker attached to his hand, feeling the boxes

Motion was not sufficient for our setup, which required precision on fingertip scale, we had to pivot to tracking the users hand with a HTC Vive tracker mounted on the users hand. We were considering to also add trackers to table and boxes for stability in the virtual representation, but instead later implemented mechanisms for calibrating these positions with the hand tracker before each session. The final physical setup can be seen in figure 1.
Software side implementation was realized in Unity which natively supports VR applications, extended by the Unity Experiment Framework (UXF) used to gather data during the participants sessions. Notable custom scripts that were added:

- A script used to represent the physical boxes in the virtual environment through a set of polygons
- A script to re-calibrate the virtual table every time the application was started
- A script to show a projection of the hand model provided by Leap (discarded)

Representing the boxes not as conventional game objects but as composed Meshes was necessary in order to be able to randomize the vertices to be deformed in each trial of the study.

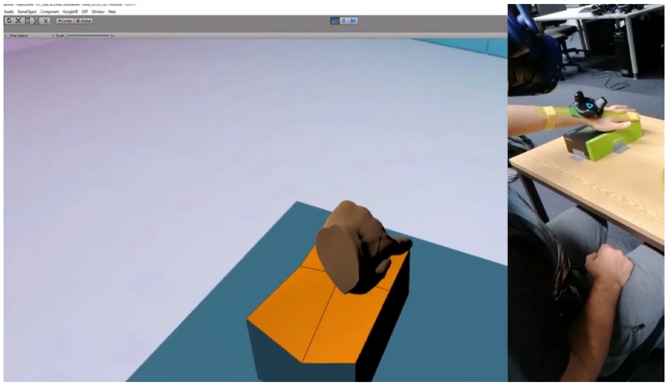


Figure 2: Here we see the concept in action, virtual against real world view

Concept

Since we ended up without Redirecting Touch, the concept was about the perception of virtual visual feedback colliding with tactile feedback from a real world object in a different way then originally intended. The visual feedback should be accurate on one box and inaccurate, due to a slight deformation, on the other. Then the participant should tell which one he perceives as higher, trying to trick him into not being able to distinguish between an accurate mapping of a real world object and a slight, but possibly visible seen deformation. The participant also knows that the two real boxes are not deformed and identical, but even then, or especially then we want to see whether the participant notices the deformation enough to tell the difference correctly.

STUDY

After the participant filled out the questionnaire and before the session started, we attached the hand-prop onto the participants left arm (regardless of the participants favoured sided hand), the participant then sits down centered in front of the table. One session consists of 20 randomized trials, containing and testing 5 different deformation amounts paired with 4 different corners. Each trial one of the two virtual boxes is deformed and the other corresponds to the real box. The deformed box is chosen random. The participant's task is to compare the height of two corresponding corners of the two boxes and decide, which one he/she perceives as the higher one (see 2). Afterwards the information of which corner the participant has chosen is compared to which corner was actually deformed and then the result of this comparison is stored in our data construct.

Participants

For the study we had 5 external participants along with ourselves for a total of 8 people tested. The background in terms of experience with VR and virtual studies/applications in general varied greatly between not at all and very experienced. The subjects were exclusively university students, coming from several different fields of study. The ages ranged from 20 to 32 with mostly male participants.

Materials

The materials used in the project were two identical cardboard boxes, affixed onto a wooden table with tape. All objects dimensions were then measured and integrated into the corresponding virtual objects in unity. Furthermore a ruler was used as a rail to keep the user from bending their index finger, because due to only a static hand model instead of the users tracked hands (e.g. provided by the Leap sensor) this would have broken the immersion.

RESULTS

Results were collected by the UXF automatically and stored in a pre-defined structure, the most important values we wanted to evaluate with this was the deformation amount as to actually finding a threshold at which users were most likely not to choose the correct box anymore, also we needed to capture which of the two boxes was deformed and which of them the participant has chosen. Also we felt like it was a viable information to check which of the corners of the morphed box was highlighted, as to examine whether there was a difference between the likeliness of the front corners (towards the participant) to be identified correctly as opposed to the back corners. Then the results file for each participant would be processed through another evaluation script arranged for a pyschometric study, that would return a sigmoid function showing the relevant values, namely the maximum value that could be chosen to still achieve the illusion as well as the maximum value at which the immersion will completely fail, which we wanted to find out in the first place.

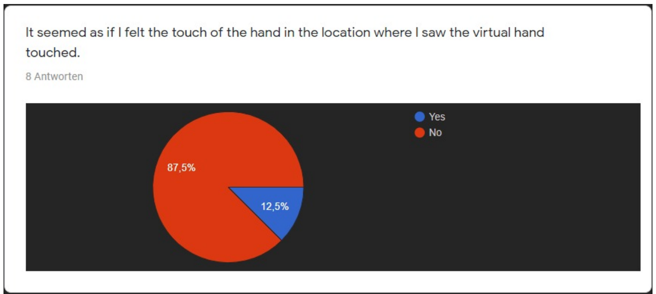
Unfortunately all the results we have got were pretty one-sided, with most participants easily being able to tell the correct answers for almost all the corners. Only some particip

Questionnaires

Before the experiment began participants filled out a "3D UI Experiment" questionnaire about related experiences in virtual experiments, both in person and on screen, as well as medical conditions or other handicaps that might obfuscate the experiments outcome. After all trials were finished we asked about System Usability Scale (SUS) for gathering insights on the handiness of our experiment as to find opportunities for technological improvements. In addition the participants also answered the Slater-Usoh-Steed Questionnaire (SUSQ), designed for the user to rate their sense of reality in the virtual environment based on real world experiences. Our post-questionnaire then asked about the perception of the virtual hand which already shows that our representation was not quite as accurate as intended as seen in Figure 2.

DISCUSSION

In general we ended up somewhere different than planned. Both of the initial illusions we focused on did not work out for technical reasons in regard of the time given for this project. Simply said, we set up a study about, whether participants would be able to differentiate between an accurate and a slightly inaccurate virtual representation of a real world object. As the project went on towards the end and time became shorter shorter, we hurried to collect the data, but in the end we ended up with unusable data. The core results were useless



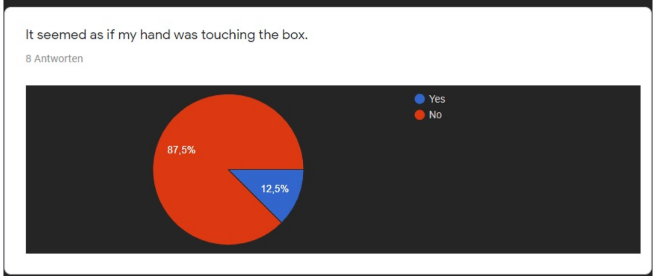


Figure 3: The results of the Questionnaires regarding virtual body ownership

due to methodical errors and time constraints. Although the project went on with many difficulties, implementation has been furthered and knowledge has been gained:

First, the "Elongated-Arms Illusion" has either to be implemented without leap motion technology or by using it, the sensor and it's data transformation/overpass have to be pinpoint integrated in order to be able to project precise hands and hand-movements, so that it can be used to record viable data. Second, the "Redirected Touch Illusion" needs to be achieved witch some sort of precise hand representation technology, like mentioned above or by using a tracked glove like by Kohli et al. [2]. In Addition to the tracking technology the virtual hand needs to clip unnoticeable onto the edges of the virtual objects to achieve the collision of two different perceptions: the visual feedback of touching and staying the virtual edges, even though they are off set and the haptic feedback of touch an edge. Third, both illusions must be able to be used simultaneously (Also from a technical standpoint).

A simple approach as we had to fall back to is simply not suited for pinpoint measurement of perceived feedback in a virtual environment while also interacting with real world objects as seen in Figure 2.

CONCLUSION

In retrospect, several frustrating issues we encountered could've been avoided by testing out the technological basis first, since most of the project's time went into troubleshooting and finding out, how the foundation we build our original thesis and intention on is simply not suited for experiments as we planned in the beginning. As we proceeded to minimize the experiment setback by setback, we conclude, that before joining various different illusions and technologies into one interaction, each one needs to be successfully replicated first, then the various technologies should brought into one environment, able to interact with each other. That is then the basis for the study. While measuring the influence of the different illusions, some other imported topics should be covered as well, e.g.:

- Does it matter whether the real boxes are seen?
- Does the participant simply accept the contradicting feedback or doesn't s/he notice it?
- Is the effectiveness of each illusion depending on the immersion of the participant in the virtual environment?

Future Work

Further work on this project would allow for several more features to increase a) the immersion of the user in the environment and b) different approaches of illusion. Immersion could be drastically increased by adding redirection of the virtual hands on the boxes to avoid the users virtual fingertip clipping into the virtual box or having a noticeable gap to it.

Another approach would be to take back up the projection of the virtual hands, extending the setup so that the user has to do the same task, just further away and with accelerated hand movements as described in the idea section. This would increase the difficulty to estimate the dimensions of the object even more, firstly because of less precise controls due to the acceleration, and secondly due to the visual distance to examined object and hand. Additionally of interest on that approach would be investigating the effects on the feeling of ownership of the virtual body.

REFERENCES

1. Parastoo Abtahi and Sean Follmer. 2018. Visuo-haptic illusions for improving the perceived performance of shape displays. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.
2. Luv Kohli, Mary C Whitton, and Frederick P Brooks. 2012. Redirected touching: The effect of warping space on task performance. In *2012 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 105–112.
3. Michael Rietzler, Florian Geiselhart, Julian Frommel, and Enrico Rukzio. 2018. Conveying the perception of kinesthetic feedback in virtual reality using state-of-the-art hardware. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.