Scaled Passive Haptic Props for Virtual Reality

Riyaadh Abrahams
University of Cape Town
South Africa
abrriy002@myuct.ac.za

James Gain
University of Cape Town South
Africa
jgain@cs.uct.ac.za

ABSTRACT

VR has been reaching more homes in the past few years. Devices such as the Oculus and Vive as made VR more accessible and affordable. This has sparked an increase in the development of VR games and experiences. We have noticed that one of the biggest problems today is the ability to interact with these virtual worlds. The hand tracking and controllers allow us to do this, but everything we do is weightless as we feel no forces while interacting with virtual objects. We explore different techniques for haptic feedback, which aims to solve this problem. We look at active and passive haptic devices, which each have their benefits and limitations. It is found that active haptics are more flexible and general purpose, while being more complex and costly to engineer. As opposed to passive haptics, which is much easier to develop, and with the use of clever perception illusions, can be quite powerful. We believe that it takes a combination of active and passive haptics to create good experiences while keeping things practical and affordable. This will allow the creation of mainstream consumer devices that still provide solid haptic experiences.

1. INTRODUCTION

There are many sensory modalities involved in creating a virtual reality experience. The most explored modalities are the visual and audio senses. Virtual reality technology has vastly improved in these capabilities in the last decade. We are getting close to photorealistic graphics. 3D audio has also greatly improved realism and immersion in virtual environments. Another important method in achieving immersion in VR is haptic feedback. This is important when we want to interact with these virtual worlds, instead of being static observers. There has been lots of research in tracking as well as haptic feedback, but not many successful products in the mainstream VR market. We believe this is an important field in achieving true immersion. There is Haptic technology, haptic perception and haptic communication. [Sharma et al. 2011]. We want to use haptic technology devices to simulate haptic perception, which is the process or recognizing objects through touch.

Haptic feedback has many sub areas. It can mainly be divided into active haptics and passive haptics. Active haptics (Force Feedback) makes use of haptic interfaces to simulate forces on our bodies, usually to help with interacting with virtual objects. Passive haptics makes use of static props to help provide realism to virtual worlds. A good example of this is a physical sword that is visually represented by a virtual sword. These passive props are combined with a visual representation to create multi modal 3D environment. We will be exploring these more deeply and examine the benefits and limitations of various implementations.

2. FORCE FEEDBACK

Figure 1 - User operating the exoskeleton [Gupta and O'Malley 2006]

Force feedback can be categorized into kinesthetic feedback and tactile feedback. kinesthetic feedback are things we feel in our muscles and tendons when forces are applied to them. It helps us identify the shape and structure of objects and is closely related to hand eye coordination. Many of these systems are created by some sort of external force on our hands and body. These systems vary in the size and weight and degrees of freedom. Degrees of freedom (DoF) refer to the number of ways a rigid object can move through three-dimensional space. In the case of haptic technology, it is the number of ways our arms can move while bound to a haptic device. Degrees of freedom are an important limitation to consider as it can affect the practical use cases of the haptic interface. A popular technique is using mechanical joints or links to our hands and fingers that apply forces and lock the movement in place at calculated positions in space. These are powered in a variety of ways, including pneumatics, hydraulics and electrical motors. Kinesthetic feedback is used extensively in surgical machines [Schostek et al. 2009]. Tactile feedback is sensed in our skin and especially our fingertips. It allows the detection of textures of objects. Both systems can help us increase immersion in virtual environments.

Kinesthetic feedback devices such the haptic Arm Exoskeleton [Gupta and O'Malley 2006] have many practical benefits, such as training and rehabilitation. This consists of an exoskeleton that provides kinesthetic feedback to the joints of the lower arm and wrist of users. It has 5 degrees of freedom and can simulate large forces on the hands and arms. Some of the limitations are that the devices must be attached to the ground so there is no mobility of the user. There are also some limitations on the movement of the elbow. Researchers were eventually able to create the MGA Exoskeleton, an improved exoskeleton design [Carignan et al. 2009]. The overall function was similar as it provided force feedback to the user’s arms. One of the biggest differences is that they had a second haptic interface to interact with the upper arm as well. So instead of only the wrists and elbow, the entire arm was involved. This system provided 6 degrees of freedom which is an increase in the previous 5DOF.

Figure 2 - The MGA Exoskeleton [Carignan et al. 2009]

Another big improvement is the direct integration with Virtual environments. These devices can become large and heavy. There also ways of creating lightweight devices. Dexmo [Gu et al. 2016] is a lightweight mechanical exoskeleton that provides force feedback on the fingers. This is a good example of kinesthetic feedback. It provides 2 degrees of freedom for each finger. Digital actuators are used to lock the joints in place, and this provides the actual force and feeling of touching virtual objects. Dexmo is small and can be operated by an 800mAh battery. It is also much safer than larger pulley-based systems. They mention one of the key limitations is that is only provides binary haptic feedback, which means you can tell when an object is there but cannot tell anything about how hard or soft it is. A similar lightweight device is the Wolverine [Choi et al. 2016] which is also a mobile exoskeleton that attaches to the hand. The device consists of multiple types of joints which allow for more freedom of movement. They use a brake system to stop any movement. They combine this with sensors to track the locations of fingers. This allows them to simulate the feeling of different types of shapes.

Tactile feedback devices allow us to feel the texture of virtual objects. A haptic touchscreen was created to help teach visually impaired learners math concepts.[Toennies et al. 2011]. Actuators was connected to an LCD screen to help create the tactile haptic effect. They created software that would generate lines and dots and using the haptic feedback, help users find various objects on the screen. They made use of audio as well to assist the haptic technology. User studies were conducted and showed some success. Although there was no clear outcome on the correct combination of audio and haptic feedback. Tactile feedback can also be used in product design. Researchers created a Haptic Dial System [Kim et al. 2008] to help in prototyping various knobs and dials. An example is a washing machine knob. They used motors so simulate different torque profiles along the rotational path. They were also able to switch the knobs with different shapes and sizes as this allowed prototyping of more products. They also combined the haptic feedback with visual and audio to create a true multi modal system. Many VR controllers have some form of vibrotactile feedback. This is especially useful when colliding with virtual objects. There are various factors that can impact the quality of the haptic feedback. These include type of motor, number of motors, alignment of the motors, and the intensity of the vibrations [Schätzle et al. 2006].

3. PASSIVE HAPTICS

Passive haptics is when virtual objects have a 1 to 1 mapping to real world objects. This allows for greater immersion without having to build complex electronics and robotics. A simple example of passive haptics is augmenting a virtual world with physical objects. [Insko et al. 2001]. One of the biggest immersion breaking situations in VR is when you pass through another object. This can be reduced by adding physical objects in the same location as the virtual object. Insko did some experiments by augmenting a VR cliff environment and added a physical ledge prop. They found that users experienced the environment as more realistic with the passive haptic prop. This was evidenced in increased heart rates and skin conductivity were higher.

Passive haptics also provide the illusion of larger props and can be felt using smaller props. Researchers were able to simulate the feeling of holding a full-sized sword, using a much smaller prop. This is achieved using the haptic shape illusion [Fujinawa et al. 2017]. One of the issues that immerges with passive haptics arise when we need to scale our experiences to many virtual objects. We cannot have a physical prop for every weapon in a VR game. There is a methods called **“haptic retargeting”**, that leverages the dominance of vision when our senses conflict” [Azmandian et al. 2016]. This technique allows a single prop to provide passive haptics to multiple virtual objects. This is achieved by manipulating the world or the body to more accurately match the prop. The creators of VRGrabbers[Yang et al. 2018] used this technique to create a controller in the shape of a grabber or tongs. It allows you to grab things in the virtual world which making you feel like you are grabbing it. What happens is the forces of the grabber pressing against itself are felt when it is closed and empty. The Visual representation is manipulated to make it seem like some object is in between the grabber tongs. The haptic retargeting allows the visual senses to be more dominant and therefore, you feel like you are grabbing something. The Vive tracker was used to track the grabber in the virtual world. Haptic retargeting works by using various warping techniques. Mahdi [Azmandian et al. 2016] speaks about body, world and hybrid warping. Body warping is when the virtual representation of the user’s body is altered such that the user contacts the real-world object at the perfect moment. World warping is when you alter the world coordinate system to allow alignment with real world objects. Hybrid warping is a mix of the 2, which allows for a more effective illusion. If used correctly, these techniques can even change the shape of real-world objects. Keigo [Matsumoto et al. 2017] made use of body warping, and rotational world warping to change the shape of a table. They were able to successfully create the illusion of a triangle using only a square table. More warping techniques are being developed. Matthews [Matthews et al. 2019] was able to combine body warping with a new “interface warping” to create a virtual interface of buttons using only 2 buttons on a panel. The one button was used as a warp origin to assist the haptic retargeting algorithms. Using this technique, any virtual interface layout could be created if it was inside the bounds of the physical panel and the algorithm would handle the retargeting. This allows flexibility in interface design using a simple physical object.

Technique	*Type*	*Description*
Kinesthetic feedback	Active	kinesthetic feedback are things we feel in our muscles and tendons when forces are applied to them.
Tactile feedback	Active	Tactile feedback is sensed in our skin and especially our fingertips. It allows the detection of textures of objects.
Passive haptics	Passive	Passive haptics is when virtual objects have a 1 to 1 mapping to real world objects.
Haptic retargeting	Passive	Haptic retargeting allows a single prop to provide passive haptics to multiple virtual objects.

Table 1 - Summary of haptic feedback techniques

4. DISCUSSION/ANALYSIS

Each technique discussed are useful to virtual reality applications. They each have the benefits and limitations. Active haptics allows for a rich experience by applying forces on our hands and arms. You can experience objects of almost any shape and size. The more elaborate sensations require larger engineered solutions. This was seen in the MGA Exoskeleton [Carignan et al. 2009]. Although the experiences that can be achieved are vast, the practical use cases are limited due to the cost of engineering and low portability. Large exoskeletons will probably not be in every household, but in specialized facilities such is rehabilitation and training centers. The smaller, lightweight exoskeletons are more practical and could possibly be used more by consumers. They would work more on the fingers, allowing the simulation of smaller virtual objects. This could be combined with good software design to create immersive experiences. Apart from these kinesthetic feedback devices, tactile devices would add another dimension to the perception of these virtual objects. The combinations of these active haptic techniques could be used to create well rounded practical VR controllers. Even lightweight active haptic devices require engineering and manufacturing. This is where passive haptic devices shine. It is not required to be an engineer to build passive haptic devices. Most of the hard work is done on the software side using tracking techniques. Haptic retargeting allows the use of a single cube to apply haptic feedback to any number of virtual cubes. This is a powerful technique that could have many use cases in modern VR applications. Another practical technique is the haptic shape illusion, which allows virtual objects to be much larger than the passive prop. Even though it is easy to develop a passively tracked sword, it is impactive to be swinging a full-sized sword in most consumer homes. This is where perception-based illusions will benefit us. Some of the limitations of passive haptics are that we do not get any force feedback unless there is a 1 to 1 mapping to every virtual object in the scene. We can combine passive and active techniques to increase the realism while keeping things as simple as possible.

5. CONCLUSION

The goal of VR has always been to increase realism and presence in virtual environments. We want to improve things that increase realism and reduce everything that brings us back into the real world. Now, the biggest problem with VR is interaction. We cannot feel the objects in front of us. Hopefully all these haptic feedback technologies will help us solve this problem. Over time, we will find the correct combination of active and passive devices to increase realism and presence. This will allow us to create truly amazing experiences while also having many practical uses.

6. REFERENCES

AZMANDIAN, M., HANCOCK, M., BENKO, H., OFEK, E., AND WILSON, A.D. 2016. Haptic retargeting: Dynamic repurposing of passive haptics for enhanced virtual reality experiences. *Proceedings of the 2016 chi conference on human factors in computing systems*, 1968–1979.

CARIGNAN, C., TANG, J., AND RODERICK, S. 2009. Development of an exoskeleton haptic interface for virtual task training. *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 3697–3702.

CHOI, I., HAWKES, E.W., CHRISTENSEN, D.L., PLOCH, C.J., AND FOLLMER, S. 2016. Wolverine: A wearable haptic interface for grasping in virtual reality. *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 986–993.

FUJINAWA, E., YOSHIDA, S., KOYAMA, Y., NARUMI, T., TANIKAWA, T., AND HIROSE, M. 2017. Computational design of hand-held VR controllers using haptic shape illusion. *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology*, 1–10.

GU, X., ZHANG, Y., SUN, W., BIAN, Y., ZHOU, D., AND KRISTENSSON, P.O. 2016. Dexmo: An inexpensive and lightweight mechanical exoskeleton for motion capture and force feedback in VR. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 1991–1995.

GUPTA, A. AND O'MALLEY, M.K. 2006. Design of a haptic arm exoskeleton for training and rehabilitation. *IEEE/ASME Transactions on mechatronics 11*, 3, 280–289.

INSKO, B.E., MEEHAN, M., WHITTON, M., AND BROOKS, F. 2001. Passive haptics significantly enhances virtual environments. .

KIM, L., HAN, M., SHIN, S.K., AND PARK, S.H. 2008. A haptic dial system for multimodal prototyping. *18th international conference on artificial reality and telexistence (ICAT 2008)*.

MATSUMOTO, K., HASHIMOTO, T., MIZUTANI, J., ET AL. 2017. Magic table: deformable props using visuo haptic redirection. In: *SIGGRAPH Asia 2017 Emerging Technologies*. 1–2.

MATTHEWS, B.J., THOMAS, B.H., VON ITZSTEIN, S., AND SMITH, R.T. 2019. Remapped Physical-Virtual Interfaces with Bimanual Haptic Retargeting. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 19–27.

SCHÄTZLE, S., HULIN, T., PREUSCHE, C., AND HIRZINGER, G. 2006. Evaluation of vibrotactile feedback to the human arm. *Proceedings of EuroHaptics*, 557–560.

SCHOSTEK, S., SCHURR, M.O., AND BUESS, G.F. 2009. Review on aspects of artificial tactile feedback in laparoscopic surgery. *Medical engineering & physics 31*, 8, 887–898.

SHARMA, N., UPPAL, S., GUPTA, S., PATIALA, V.B.P.O.R.D., AND PANIPAT, S.D. 2011. Technology based on touch: Haptics technology. *IJCEM International Journal of Computational Engineering & Management 12*.

TOENNIES, J.L., BURGNER, J., WITHROW, T.J., AND WEBSTER, R.J. 2011. Toward haptic/aural touchscreen display of graphical mathematics for the education of blind students. *2011 IEEE World Haptics Conference*, 373–378.

YANG, J., HORII, H., THAYER, A., AND BALLAGAS, R. 2018. VR Grabbers: Ungrounded Haptic Retargeting for Precision Grabbing Tools. *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology*, 889–899.