Touchless Haptic Feedback for VR Rhythm Games

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ABSTRACT

Haptics is an important part of the VR space as seen by the plethora of haptic controllers available today. Recent advancements have enabled touchless haptic feedback through the use of focused ultrasound thereby removing the need for a controller. Here, we present the world's first mid-air haptic rhythm game in VR and describe the reasoning behind its interface and gameplay, and in particular, how these were enabled by the effective use of state-of-the-art ultrasonic haptic technology.

Keywords: haptics; ultrasound; HCI; VR; rhythm games.

Index Terms: H.5.1 [Human computer interaction (HCI)]: Interaction devices—Haptic devices; H.5.2 [Human computer interaction (HCI)]: Interaction paradigms—Virtual reality

1 INTRODUCTION

Multimodal interaction with 3D objects has often been alluded to by visionaries as far back as Sutherland's ultimate display [4], where computers can "control the existence of matter" and the user can see and freely interact with it. Huge technological advancements have been made since then, bringing Virtual Reality (VR), and all of its variations (AR/MR/XR etc.), closer and closer to the mass market as demonstrated by the number of consumer VR platforms being launched this year. These platforms feature diverse capabilities that including gaze selection, 360° motion and 6 degrees of freedom hand tracking, and may also be accompanied by a range of peripherals such as hand-held controllers, wearable gloves, and even full-size exoskeleton suits.

Haptic feedback can significantly increase the performance of VR applications [3]. The design and effectiveness of haptic devices however depends on the purpose of use and the targeted users. In this extended abstract, we present and demonstrate a touchless (i.e., non-wearable) haptic platform and its effective use in VR rhythm games. The haptic device we have developed combines off-the-shelf hand tracking solutions with the advanced manipulation of focused ultrasound to remotely stimulate receptors in various parts of the hand. For this novel haptic technology to lend itself to high end VR applications such as gaming, significant improvements needed to be made since the early day mid-air haptic displays [1].

The goal of our present research was not the accurate haptic reproduction of complex 3D objects but rather the enhancement of the overall VR experience. Broadly speaking, this haptic enhancement refers to the user experience and interaction techniques while combating VR sickness. The result of our research was a futuristic looking (Tron-like) haptic rhythm game in VR which is something between a race-car driving game and the well-known Guitar-Hero gameplay. Instead of a guitar shaped controller however we use focused ultrasound to emulate the tapping sensation off the skin of the bongo drums. Briefly, as musical notes come in through the "note highway", the player taps or swipes them left or right to turn using their bare hands [5]. Here, we will limit the discussion to the demo's physical and user interface design, and defer further in-depth technical and user studies for future work. Our main contribution is the demonstration of state-of-the-art touchless mid-air haptic feedback capabilities, and a discussion on best haptic design practices for their application in VR rhythm games. We conclude with the generalizable knowledge we have extracted to do with haptics and interaction design

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Figure 1: Photo of the demonstration setup, the UHDK5 device, and the LEAP motion controller.

2 DEMONSTRATION SETUP

The demonstration is set on a tabletop and consists of the HTC Vive VR headset with headphones and a single Lighthouse, and a gaming laptop, an Ultrahaptics TOUCH Development Kit (UHDK5), and a LEAP Motion controller (see Figure 1). The LEAP controller and the UHDK5 are pre-calibrated. To align the graphics to the UHDK5, we place the Vive controller flat on the UHDK5. When the trigger on the Vive controller is pressed, the camera is moved so that UHDK5 is aligned with a known point in the virtual scene

We have designed the setup, the user interface and rhythm gameplay as to utilize the strengths of the components used. Namely, we made sure that the position of the LEAP Motion controller camera has a direct and clear field of view of the user's palms. Most of the game interactions are also designed to be actioned with open palms. This improves the tracking accuracy of the LEAP and also improves the haptic sensations achieved by focused ultrasound vibrations since the Pacinian corpuscles (the mechanoreceptors responsible for detecting high-frequency vibrations) are most dense there. Finally, we decided on a standing up game, rather than a sitting down, since this can increase physical activity and allows for further immersive VR experiences.

3 GAME AND INTERACTION TECHNIQUES

The game is designed in a walk-up-and-use manner without the need for additional user instrumentation. Once in VR, the user sees her two avatar hands and a left-hand palm imprinted on a virtual table in front of her that she is expected to reach out and touch with her left hand. This activates the game. There are very few in-game text cues with instructions supplemented by a short tutorial to learn the interaction techniques. The menu is revealed and unfolded to the right by opening the left palm face up (see Fig. 2). Selection is made by the right hand and the note highway appears.

There are two types of in-game hand gesture interactions: tap and swipe (for both left and right hands) that need to be accurately actioned within a time window interval of approximately 1 second (depending on the difficulty level selected). Each of the gestures is associated with a visual symbol on the note highway representing a

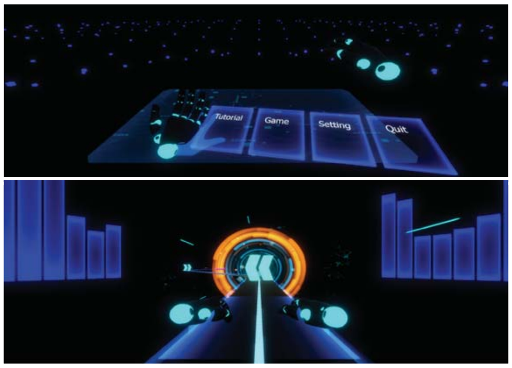

Figure 2: The start menu and the “note highway”.

request for a tap or a swipe action. As the song progresses, the symbols indicating actions travel down the highway towards the player’s location in time with the music. Flat cube symbols correspond to taps, while guillemets (sideways double chevrons) correspond to swipes. The tap symbols are colored blue and red and are positioned in the left and right highway lane respectively. Once a note reaches the player’s vicinity the player must tap the indicated note with the correct hand. Success or failure will cause the avatar hand to change color, the tap symbol to shatter, and a tapping sound to be played. The guillemets are positioned in the center of the highway and are immediately followed by a 45-degree turn in the pointing direction. Once a guillemet reaches the player’s vicinity, the player must swipe into the pointing direction with an open flat palm using the outer hand. For example, for “<<” the user should swipe from right to left using her right hand. To mitigate VR sickness, we keep the orange ring-portal at the horizon fixed, even during the meandering of the note highway. There is also a fixed score board fixed to the top left corner of the player’s field of view.

4 Haptics

Rhythm games in general require tight synchronicity between visual, audio, and haptic cues. Therefore, the haptic engine and haptic display must meet certain requirements on, *inter alia*, latency, haptic strength, dynamicity (i.e., haptic refresh rate in both space and time), output reliability, interaction space, and ease of implementation. We briefly describe how these have been met.

The UHDK5 is a 14x14=196 phased transducer array that can be used to focus 40 kHz ultrasound at a specified location in three dimensions. The *(x,y,z)* coordinates for creating one or multiple focus points (e.g., at the center of the user’s palm or fingertip) are obtained from the LEAP Motion API and can be updated 400 times a second. This update rate is paramount in meeting latency, dynamicity, and reliability requirements, and also for generating consistent haptic effects. For instance, for a tactile sensation to be perceived the acoustic radiation force is amplitude modulated at 200 Hz as to create small localized skin displacements, the focus coordinates of which can be dynamically relocated 400 times a second. The result is perceived by the user as a strong and dynamic haptic effect. The effective ultrasonic focusing (haptic interaction) region of this device is about 90 degrees wide and up to 50 cm far. This generates more than enough of an interaction volume for the two-hand bongo playing game. The Ultrahaptics device has an API (written in C++ and C# with Unity bindings) which has *(x,y,z)* position coordinates as one of its main inputs needed to generate up to 4 amplitude modulated focus points, thereby making the haptification of hand gestures straight forward as long as they are *i)* detected by the LEAP Motion, and *ii)* within the focusing region of the Ultrahaptics device. The SDK is integrated as a plugin to the Unity game engine, with haptic states being refreshed on a frame by frame basis and in sync with the graphics and the audio outputs.

All user interactions described in the previous section are haptified using focused ultrasound. For example, in the game activation scene, rapid haptic palpations are generated on the user’s left hand when in contact with the imprinted palm. Specifically, the coordinates of four focus points at every time instance are chosen at random on the whole palm. These coordinates are randomized and regenerated every 0.05 seconds. During menu selection, two focus points are pulsed on/off on the selecting hand’s index and middle finger tips. Due to the dynamic nature of the in-game interactions, designing and implementing mid-air haptics was extremely challenging. At every tap gesture, two focus points are projected 4 cm below the tapping palm’s center. The 4 cm offset of the focus points compensates for any lag during the downward tapping motion of the user’s hand and the time of flight needed for the ultrasonic waves to reach the user’s palm. During the swipe gesture, four focus points forming a straight line, that is parallel to the index finger, are generated starting at the bottom of the index finger and offset outwards towards the thumb by 4 cm. The offset compensates for the lateral swiping motion of the user’s hand. The line is pulsed on/off every 0.1 seconds creating the haptic illusion [2] of brushing over a moving object. A schematic of the haptics associated with user interactions is shown in Figure 3.

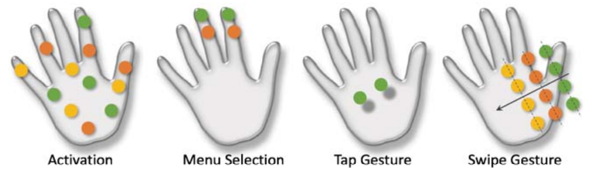

Figure 3: The locations of touchless haptics on the hand during different interactions and at different time instances. Green, orange and yellow are time separated by 0.2 seconds each.

5 Conclusion

We have presented the world’s first mid-air haptic rhythm game in VR and have described the reasoning behind its interface and gameplay, and in particular, how these were made possible by state-of-the-art ultrasonic haptic technology. Significantly, we have demonstrated that the UHDK5’s haptic engine and ultrasonic phased array are able to solve, manipulate, and display the desired acoustic pressure field in a useful interaction space while reliably producing complex haptic effects in real-time with minimal latency. What’s more, the haptic effects were seamlessly implemented within a dynamic VR environment, that of a rhythm game. Never before have mid-air ultrasonic haptics met such high performance goals. To that end, we have learned that mid-air haptic rendering design need not accurately mimic the physical shape of what we see but rather its dynamics or motion. Going forwards, we expect that prediction algorithms and higher accuracy hand tracking could be used to further improve haptic feedback latency and resolution.

Acknowledgments

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References

[1] Takayuki Iwamoto, et al. "Non-contact method for producing tactile sensation using airborne ultrasound." Haptics: Perception, Devices and Scenarios (2008): 504-513.
[2] Margaret Minsky, et al. "Feeling and seeing: issues in force display." *ACM SIGGRAPH Computer Graphics*. Vol. 24. No. 2. ACM, 1990.
[3] Robert Stone. "Haptic feedback: A brief history from telepresence to virtual reality." *Haptic Human-Computer Interaction* (2001): 1-16.
[4] Ivan E. Sutherland, "The ultimate display." *Multimedia: From Wagner to virtual reality* (1965).
[5] www.instagram.com/p/BXGD7kkl1Y3