Wearable Controller with Texture Feedback

A Texture based Controller for Multitouch Interaction

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ABSTRACT

As the visual contents of virtual reality have advanced significantly, Research in HCI has addressed improving a range of haptic feedback other than vibrotactile feedback. This study focuses on texture haptic feedback and improving users' holistic experience of receiving texture feedback. Our wearable texture feedback controller enabled users to receive texture haptic feedback in a manner that resembles their real-life experience. As the name suggests, the controller is attached to a user's wrist, and the wheel with texture elements comes up only when the user touches an object in VR. This design allows users to feel texture feedback with their whole hands, which improves the user experience of VR compared to previous research in which users place one fingertip to feel the feedback.

KEYWORDS

Virtual Reality, Haptic feedback, Wearable device, Texture feedback

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1 INTRODUCTION

In cartoons and movies, many fictional characters use 'cool' tools to show examples of what people dream of, such as a time travel machine. Developing these dream tools then seemed impossible, but some became real in the 21st century. Virtual Reality (VR) is one example. Although movies showed that characters in the story wear goggles to walk around a virtual world, many people did not expect to immerse themselves in the world of games.

Since the arrival of VR, the quality of VR has improved significantly. However, while VR's visual content has been enhanced for over a decade, the haptic feedback rendered for commercial VR is only vibrotactile feedback [3]. Many companies have invested in developing VR controllers that generate different types of haptic feedback other than vibration. Teslasuit produced wearable suits that give users more detailed feedback, such as tense and nerve stimulation [10]. These new technologies are available to everyone to order online, although it costs more than 10 thousand dollars, which is unaffordable to most people. Many researchers worked on generating different types of haptic feedback. Still, most of them focus on generating accurate feedback, and these controllers do not always consider how people actually touch objects in real life. For example, people use their entire hand to examine the roughness of the surface in real-life situations rather than using one fingertip. However, a hand-held VR controller generating texture feedback was designed for users to place a finger on a material to experience the feedback [1].

To address such limitations of haptic feedback of VR controllers, we developed a wearable texture feedback controller that enables users to feel materials with their entire hand, enhancing the user experience in VR, which was not always shed light on in developing VR.

This paper makes the following contributions:

1. We developed a wearable texture feedback controller that enables users to feel materials they touch in VR in a manner that resembles their real-life experience.

2. We addressed improving the user experience in VR, which is not often given consideration in the early stage of prototyping in other research.

2 BACKGROUND RESEARCH

As the technologies have advanced, many researchers and companies have researched producing different haptic feedback for VR controllers beyond vibrotactile feedback, including thermal, gravity, pressure and texture. We will look at prior research to discover how texture haptic feedback systems have been developed and their challenges. Culbertson et al.[4] recorded data of users' motions on different types of surfaces and created haptic texture models from it using vibrotactile feedback. The research did not come with the results of user testing, which made it unclear whether users were satisfied with the quality of the feedback. The other research built a novel technology that generates texture feedback using vibration [9]. This research created an algorithm to generate more realistic feedback measured with three different categories; granularity, amplitude and timbre. The fineness of the feedback did not affect the result. Rather amplitude and timbre do matter. These studies

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played a vital role in exploring the possibilities of producing haptic textures with vibrotactile feedback.

The trend of studies of texture haptic feedback shifted towards non-vibrotactile generated recently. Shifting away from vibrotactile feedback, Kyung and Lee [7] employed a tactic array together with vibration to generate more accurate shape rendering. This allowed users to feel texture and vibration when using a pen-shape controller on the tablet. Advancing tactic array technology, many studies were able to generate different texture feedback in different ways. Benko et al. [3] 4 x 4 actuated pins were used on the surface of the finger-tip size controller generating the texture of each object. However, user testing showed the feedback produced by 16 pins was not as accurate as they expected.

Previous research showed two different ways to implement controllers with a multi-surface head producing texture feedback; a hand-held device or a robot arm. Araujo et al.[2] built a robotic arm mounted on a flat surface to generate texture feedback. This controller tracks users' hands, enabling them to develop three different types of feedback. The texture feedback head can be mounted on the robotic arm, and it touches the user's hand when they are close enough to an object in VR, and then it moves freely with their hand. It enabled the free-hand controller to render different feedback, but its movement was limited as it needed to be mounted on a flat surface. Whitmire et al. [1] developed a hand-held controller with a similar mechanism as Araujo et al. using a multi-surface head. A wheel on the controller rotates and gives a user texture feedback for an object they touch in VR. This controller's significance was the feedback's accuracy compared to prior research and no contact with the user's fingertip when they were not feeling materials. Handheld devices in previous studies constantly touched users' fingers even when they released their hands from objects in VR [4,5]. However, Whitmire et al. [1] added a motor to move the wheels up only when users contact an object in VR. It made the feedback more realistic. However, this haptic controller was designed for users to put a fingertip on the wheel to experience haptic feedback, which does not resemble typical real-life interactions.

It becomes evident that many of them focused on enhancing the accuracy of their feedback to improve user experience in VR. Yet more research needs to be conducted to explore how altering the delivery of feedback can boost the user experience of VR. A study investigating how humans show their emotions through squeezing found that people generate nuanced touch to convey different emotions [8]. Other research invented VR controllers for different types of squeezing sensations to explore how such subtle touch communication can be generated by VR haptic controllers [6]. These studies shed light on the importance of considering every detail of VR controllers to achieve more realistic haptic feedback experiences.

Learning from these previous studies, this study aimed to enhance users' experience of feeling texture feedback. The prior research showed the limitations of hand-held devices and robot arms for VR controllers producing texture feedback. We built a wearable controller. Our hypothesis is as follows: The controller, allowing users to use their hands freely, enhances their experience of VR texture haptic feedback, closely resembling the interaction of touching objects in real life.

3 DESIGN AND IMPLEMENTATION

The design goal and aim of our wearable texture feedback controller was for it to be more hands-free and interactive. Our goal and aim were predominantly derived from existing research around texture-based haptic controllers, which is explored in detail below. Our controller was developed in a way where it could be used for multi finger interaction that renders finger haptics when used within a virtual environment. For the purposes of this project, we decided to develop a 'shopping experience' virtual environment demo for the controller. In this demo, users would use their fingers to touch and feel a clothing item. When that item is touched, the controller spins the wheel to that selected texture under the fingertips. The wheel that we developed is interchangeable and contains physical clothing textures to provide haptic sensations to the user.

3.1 Wearable Texture Feedback Controller

We based the Wearable Texture Feedback Controller on Haptic Revolver. Instead of the controller being handheld, we questioned how we could make the current Haptic Revolver more novel and interactive. Hence we designed our controller to instead be hands-free and wearable on the arm. This would allow the user to interact with the controller using more fingers (figure 2). This controller, similar to Haptic Revolver, uses a wheel with textural elements on it and raises and lowers in response to its position in the virtual environment demo. In the following sections below, we describe the hardware and software components of the controller.

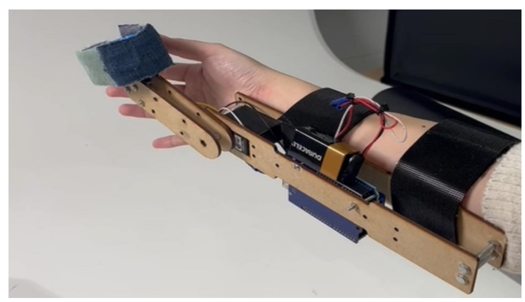

Figure 1: Wearable Texture Feedback Controller

3.2 Hardware Design and Implementation

We arrived at the design of the Wearable Texture Feedback Controller through an iterative process where each design that was created improved in terms of functionality and ergonomics. Our final design (figure 3) was created using many elements. The arm component was developed using a laser cutter with 3mm plywood material. The 60 mm wheel was designed in Fusion 360 and 3D printed. The controller has two degrees of freedom, each of which is actuated by a specific motor. A servo motor was used to raise and lower the wheel along the arm component, while the wheel itself used a DC motor. The DC motor was held together by screws and bolts to keep the wheel connected to the arm component and for the motor to also remain in place. In terms of other main hardware components, Arduino was fixed to the middle of the controller for motor control and code input. The Arduino part of the controller connects to a PC through a USB link and is powered by a battery.

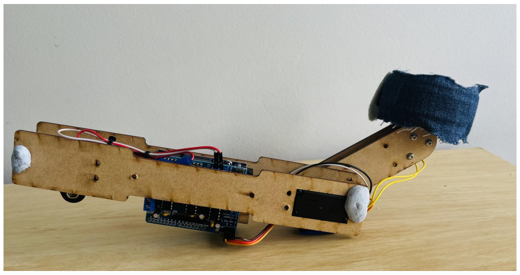

Figure 2: Final Design of Wearable Texture Feedback Controller

3.3 Software Design and Implementation

C++ code with specialised functions and libraries were predominantly used to control the movement of the DC motor and Servo motor for both the arm component and wheel accordingly. In terms of Unity and its integration with Arduino, C# (sharp) was used. This was done to integrate the controller with Unity for the 'shopping 'experience' demo to work properly. The Unity, Arduino and VR integration is explored in further detail below.

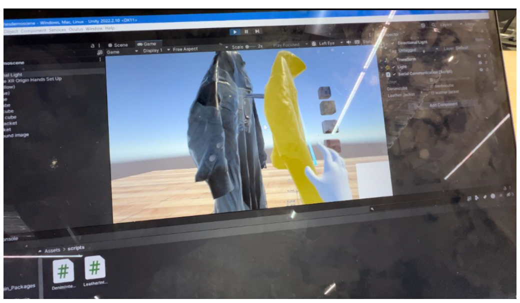

Figure 3: VR 'Shopping Experience' Demo with Hands Tracking

3.4 Unity, Arduino and VR Integration

Arduino and Unity were programmed together. Unity sends an event to Arduino whenever an object, which in this case was a clothing item, is hovered upon in the developed scene of Unity. The said event is then used to send information to Arduino, which acts upon it. If the object is hovered upon, the wheel moves up towards the fingers of the user. If not hovered upon, the wheel moves back down. Arduino was needed to know which material is being touched to actually turn the wheel and bring it to the desired texture. To create the 'shopping experience' demo, a Meta VR headset and Unity were used. The VR headset connects to the PC through a USB connection. Multiple libraries, including XR interaction toolkit and XR hands, were downloaded in Unity to visualise hand tracking through the VR (figure 4). This helped to track the controller. To obtain the shopping experience demo, a clothing store asset was downloaded for clothing items and textures. The integration of Unity, Arduino and VR headset allowed for the controller to function in the way we initially intended, matching the aim and goals for the design and implementation of our Wearable Texture Feedback Controller.

4 DEMO APPLICATIONS

Our wearable controller can be used for several applications which require texture feedback, such as a virtual clothing store, virtual housing materials store and virtual games with surface-based interaction. These applications will be further discussed below.

4.1 Virtual Clothing Store

Customers can explore and interact with virtual clothing products in a unique way using a texture-based VR controller in a clothes store setting. Through haptic feedback, these controllers allow users to simulate touch and feel the textures of various materials, such as cotton, silk, or denim. Customers may feel the softness and texture of the fabrics as if they were physically present by gliding their hands or fingers over the virtual apparel exhibited in the VR environment. With the help of this technology, customers may have a more enjoyable and realistic shopping experience, making more confident decisions about the fabrics they want. Additionally, it gives the clothing business a chance to highlight the variety of textures they provide, encouraging buyers to explore textures more thoroughly as they look for the ideal outfit.

4.2 Virtual Building Supplies Store

An engaging and interactive way for customers to interact with the products is introduced through a texture-based VR controller in a store selling building supplies for houses. This controller features haptic feedback, which enables users to realistically touch and feel different building materials like tiles, wallpaper, and flooring alternatives. Customers can explore the various surfaces in a virtual world, feeling the smoothness of marble, the roughness of stone, or the patterns of wood grain. With the use of this technology, customers have a rare chance to evaluate the materials both visually and physically to get a genuine idea of how they would seem and feel in their own homes. Customers can confidently select the ideal building materials that complement their personal aesthetic and style preferences with the texture-based VR controller, offering a completely immersive and individualised purchasing experience.

4.3 Virtual Games With Haptic Feedback

For virtual games featuring surface-based interaction, a texture-based VR controller presents a novel way to improve immersion and gaming dynamics. In order to replicate the feel and texture of various surfaces within the virtual game world, these controllers use haptic feedback. Virtual objects and environments can be physically touched and interacted with by players, who can feel the textures of smooth, bumpy, rough, and slippery surfaces with their fingertips. For instance, while navigating and grasping various handholds in a virtual climbing game, players can feel the texture of rock surfaces. Players can find hidden clues in a puzzle game by sensing changes in surface textures. In a racing game, players can also feel the roughness of various road surfaces, like asphalt or gravel, which affects how their car handles. Game designers can build more immersive and compelling experiences by utilising texture-based

VR controllers, where surface interactions become an essential component of the gaming mechanics.

5 DISCUSSION

We designed our new controller to integrate into existing VR systems, and the fundamental objective of the controller is to enrich user's virtual reality experience by providing them with a better sense of touch. Our Controller creates an immersive experience where users can interact with objects in VR in a manner resembling their real-life experience, allowing them to use their entire hand. Although we did not conduct usability testing to investigate how accurate feedback can be conveyed to users, people at the showcase at the University of Melbourne got excited when they first felt materials with our controller. They were able to feel the correct material corresponding to objects in VR (figure 4).

5.1 Challenges

We must recognise the challenges and constraints remaining despite having made some significant progress on this project.

The range of simulated materials is limited: We can only use our system to simulate a range of fabrics commonly used in everyday wear. However, this controller only conveys two different materials at the same time, although interchangeable wheels with different materials were developed. Users needed to change the wheels depending on the materials in VR.

Accuracy of haptic feedback: Although our controller can imitate different fabric textures, the accuracy of the movement of the controller should be improved in future. When the wheel rotated and came up to show the material a user was touching, the user sometimes placed their hands in between these fabrics, which did not represent the feedback they should receive from one fabric. When we presented our controller at the showcase, we needed to ask users to move slowly to have more accurate feedback. It showed us room for improvement, which is the response speed of the wheel coming up to users' hands.

Comfort and ease of use: Our goal was to make our devices as comfortable and user-friendly as possible, but one's unique hand shape or personal preference might lead to different experiences. For instance, the size of the wheel was fixed, and it was too small for people with large hands. Although we designed the attachment parts as flexible to adjust where the wheel should be set for everyone, some fixed parts could have been designed to accommodate a range of users.

5.2 Future Work

We have taken cognisance of the constraints and hence plan to improve our controllers soon. In regards to work in the future, this is what we envision. The use of advanced haptic systems can help to simulate physical fabric textures, and we can develop more accurate textures in the future with additional research on how we can improve and further refine current methods. With the possibility of simulating a wide variety of materials aside from just cloth texture alone with this technique, we could potentially replicate metal or wood as well. For example, Günther et al. [5] produced different roughness using the same material and adjusting the frictions. If we were able to add this system on our wearable controller, we can generate texture feedback for multiple materials with one wheel. We need to conduct user testing to analyze how accurately this controller responds to the actions of users in VR. It is worth checking the quality of feedback in terms of the angle of wheels, speed of the wheel's rotation, and the number of materials.

6 CONCLUSION

We presented our wearable texture feedback controller that responds to users' movements in VR accurately and generates texture feedback corresponding to the object they interact with in VR. The project has two significance: First, we considered how people interact with objects in real life, leading us to make our controller a wearable device. In this way, we achieved to produce seamless and immersive experiences in which users can feel texture elements in VR in a manner that resembles their real-life experience. Although user testing is required to improve this system iteratively to generate more accurate feedback, we showed that well-thought design considerations could enhance the user experience of VR haptic feedback.

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