Haptic-Enabled Buttons Through Adaptive Trigger Resistance

Carolin Stellmacher*

University of Bremen, Germany

Abstract

While commercial controllers for virtual reality (VR) offer a variety of components to register user input, their ability to generate meaningful haptic feedback during the interaction lags behind. This prevents users from experiencing the virtual world through their haptic sense. For example, grabbing a light virtual object feels identical to grabbing a heavy virtual object. In this workshop paper, we enrich an established input component available in any commercial VR controller with appropriate haptic rendering capabilities. As a proof of concept, we present our haptic VR controller *Triggermuscle* and its adaptive trigger to simulate weight in VR. The trigger dynamically adapts its resistance according to the weight of a grabbed virtual object: The heavier the virtual object, the higher the trigger resistance and the more force users need to apply. Our system is built into the casing of an HTC Vive controller and connects the original trigger component to an extension spring for variable resistance. We envision for the future, that VR input devices can evolve more into input-output technologies and provide meaningful and versatile haptic feedback.

Index Terms: Human-centered computing—Interaction devices—Haptic devices; Human-centered computing—Interaction paradigms—Virtual reality

1 Introduction & Motivation

Commercial controllers for virtual reality (VR) currently offer a variety of components to register user input such as buttons, grip buttons, triggers, or thumbsticks. They enable users to apply different techniques to interact with the virtual environment (VE). But in order to provide users with haptic feedback and convey a dynamic response to their actions, current commercial input devices are very limited. Haptic feedback can only be generated through vibrotactile rendering such as in the HTC Vive controller or Oculus Touch. This forbids users an appropriate haptic sensation during their interaction with the VE. For example, grabbing a light virtual object by pulling the trigger haptically feels identical to grabbing a heavy virtual object.

To improve users' haptic experience during the interaction in VR, a diverse range of mobile haptic interfaces has been explored. These technologies create haptic sensations of virtual objects and their properties such as rigidity and compliance [16] or texture and compliance [8]. Shape and texture are, e.g., rendered by tilting a platform at the user's index finger pad [1]. A different approach for virtual shapes and textures is a rotating wheel at users' fingertips [19]. Due to the rotation of the wheel, shear forces that typically occur during gliding along a surface can also be rendered. Shifting weights change the weight distribution of a controller and also enable shape perception [15]. A similar concept uses movable surface elements that increase or decrease the surface area of the controller and impact the shape perception through inertia [9]. A broader range of haptic sensations in one device is established through the combination of multiple haptic technologies [4]. The controller renders kinaesthetic forces at the index finger during grasping and touching which allows to feel the shape and stiffness of virtual objects. Additionally, a voice coil actuator produces vibrations for different surface textures.

Enabling users to haptically experience the weight of a virtual object in VR using a mobile haptic interface is particularly challenging, since no external forces can be generated to simulate the gravitational pull. As a result, various technologies have been implemented that follow diverse approaches. Haptic interfaces that are worn on users' hands and fingers investigated skin deformation by using a small belt around users' fingertips [11] or small movable plates at users' finger pads [17] to stretch the skin. This imitates the same haptic sensation when grabbing and lifting an object in real life. Another finger-mounted device creates grip forces through a brake mechanism and a sensation of virtual weight through asymmetric

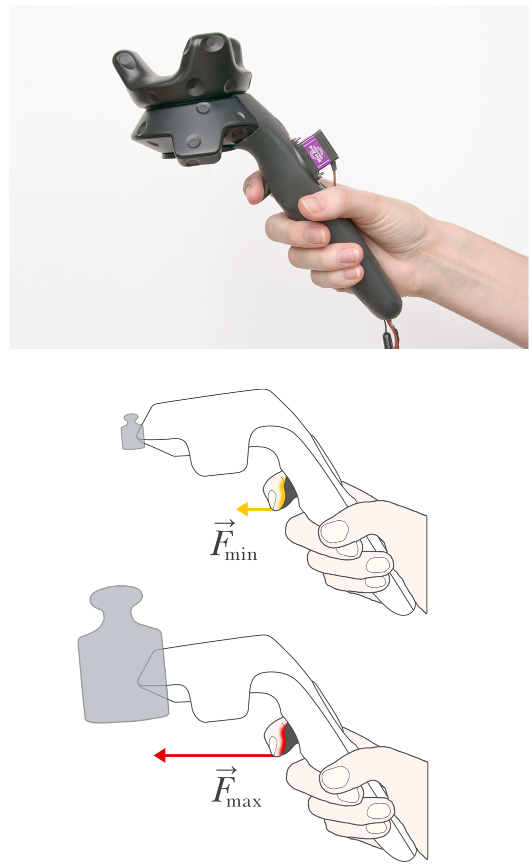

Figure 1: (top) Our haptic controller *Triggermuscle* simulates the weight of virtual objects in VR through adapting the trigger resistance. The spring mechanism for a dynamic adjustment is built into the casing of an HTC Vive controller. An HTC Vive tracker is mounted to the top to enable spatial tracking. (bottom) In combination with our used extension spring model, Triggermuscle allows continuous regulation of the resistance from approximately 4.29 N ($\vec{F}_{\text{min}}$) to 16.36 N ($\vec{F}_{\text{max}}$).

*e-mail: cstellma@uni-bremen.de

vibrations at the finger pads [3]. A different approach was explored through electrical muscle stimulation (EMS) which artificially creates a downward movement of the user's arm [10]. However, typical limitations of wearable devices are hygienic considerations, they might feel cumbersome to wear, and need to be adjustable or manufactured in different sizes to fit a diverse range of users.

In contrast, hand-held devices offer more flexibility in terms of hand sizes and comfort. To enable weight simulation with this type of controller, different mechanics have been investigated. A shape-shifting controller adjusts its surface area by changing the configuration of two attached fans [21]. Moving the controller through space enables users to perceive the respective air resistance and the varying drag and weight shift. Shifting the weight distribution of a controller was also explored to convey the weight of a virtual object [20]. While these mechanisms can render the distribution of an object's mass, they cannot render the absolute mass of objects. This was achieved by a fluid-shifting mechanism [2]. By pumping fluids between a hand-held container and a bag worn by users on their backs, the actual weight of the hand-held component can be adjusted. This is, however, limited to liquid-based interactions. While these technologies have been shown to impact users' impressions of virtual weight, they often rely on complex hardware, or can only be used for specific use cases.

In this workshop paper, we propose a new hand-held controller to simulate virtual weight in VR during the interaction. To provide meaningful haptic feedback, our approach uses an established input component of any commercial VR controller: the trigger. Its resistance is dynamically adapted according to the weight of a grabbed virtual object. Users, therefore, need to scale their applied index finger forces to grab different virtual weights: The heavier the virtual object, the more force needs to be applied to pull the trigger. As a proof of concept, we built our haptic VR controller *Triggermuscle* which can be seen in Figure 1. The mechanism is built into the casing of an HTC Vive controller and connects the original trigger to an extension spring. In combination with a servo motor, the resistance is dynamically adjusted on a continuous range.

In the following sections, we will present our implementation of the spring mechanism and an outlook towards the evaluation of Triggermuscle and its adaptive trigger. We further discuss possible use cases that extend the scope of application beyond weight simulation as well as haptic feedback for other types of buttons available in commercial VR controllers. Furthermore, we will show a video during the workshop that demonstrates our working controller Triggermuscle in a VE where virtual fruits of different weight can be explored.

We believe augmenting established input components of commercial VR controllers such as the trigger with haptic rendering could make haptic feedback more accessible for input devices in the future. Our spring mechanism is built with inexpensive hardware and can be easily tailored to various form factors, which demonstrates the potential for haptic rendering in the commercial domain. We believe extending input components with meaningful haptic feedback can shift the perspective on input devices towards an input-output capability. In addition, enriching buttons with haptic feedback is increasingly evident in the space of input device development as, e.g., Sony [13] and Microsoft [12] announced actuated triggers for their game controllers.

2 Adaptive Trigger for Weight Simulation

The concept of our adaptive trigger incorporates the perceptual mechanism of weight perception in real life. Depending on a perceived weight, humans apply an appropriate amount of grip force to successfully lift an object and at the same time to cause no damage to that object [18]. We transferred this relation between grip forces and the perceived weight to the established interaction technique of any consumer VR controller. With such devices, grabbing a virtual object typically involves pulling the trigger, which requires muscle force of users' index fingers to overcome the constant resistance. By adjusting this resisting force, substitutional stimuli [7] are displayed as weight cues and users need to adjust their index finger forces according to the weight of the grabbed virtual object. An illustration of the intended effect is shown in Figure 1.

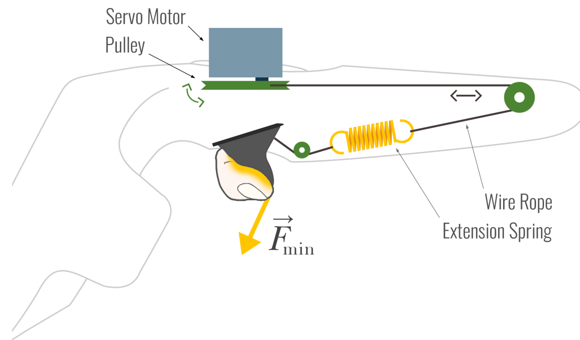

Figure 2: Schematic illustration of Triggermuscle's spring mechanism utilising an extension spring.

3 Triggermuscle

Triggermuscle was developed as a proof of concept for the adaptive trigger and to explore the feasibility of extending an existing input component with haptic rendering.

We built our spring mechanism into the casing of an HTC Vive controller and attached it to the original trigger, as illustrated in Figure 2. Pulling the trigger with the index finger stretches the attached extension spring on one end making the exerted force noticeable to users as the trigger resistance. By changing the length of the extension spring inside the mechanism before the trigger is pulled, its exerted force is modified and, thus, also the resistance of the trigger. The dynamic adjustment of the extension spring is established with a high-voltage (6.0 V) digital micro servo (BMS-210DMH) which is installed into the original trackpad component of the controller. With an attached pulley on top, the servo is connected to the extension spring via a wire rope. Changing the servo's angle rotates the attached pulley and winds the connected wire rope, thus pulling or releasing the spring. The dimensions of the controller casing allow a spring stretch of up to 20 mm. In combination with our used extension spring model, a continuous regulation of the resistance is achieved from approximately 4.29 N to 16.36 N, allowing a maximum resistance increase of over 281%. Research in the discrimination of spring stiffness showed that humans perceive a minimal difference between 15% and 22%, also known as the Weber Fraction (WF) [6].

Apart from the modified resistance, the haptic sensation of pulling the trigger is maintained, including the final *click*. An ESP32 microcontroller unit (MCU) registers the digital signal when the trigger is fully pulled, drives the servo, and communicates with Unity 2018.3 via Bluetooth. Along with a lithium polymer battery and a battery eliminator circuit (BEC) component, the MCU is carried in a small bag on the user's back. A cable connects it to the controller's bottom allowing users to move freely. The working prototype of the controller is shown in Figure 3. An HTC Vive tracker attached to the controller's top provides spatial tracking since the original tracking components were removed from the casing. The total weight of Triggermuscle (bag excluded) is 300 g, the original HTC Vive controller weighs 200 g.

Figure 3: (left) Our haptic VR controller Triggermuscle. (top right) Attachment of the HTC Vive tracker to enable spatial tracking. (right bottom) Electronic components (MCU, the battery, and the BEC) are carried in a small bag.

4 Outlook

As the next step, we want to evaluate Triggermuscle in a user study and explore the capacity of the adaptive trigger to haptically display virtual weight. In particular, we aim to investigate users' ability to discriminate between different intensities of the trigger resistance as well as the effect on weight perception in VR.

Similar evaluations of other haptic interfaces [5, 14, 17] are conducting a psychophysical user study to identify the just noticeable difference (JND) of the provided haptic stimuli. This would determine the necessary minimum adjustment of the trigger resistance to achieve a just noticeable effect in users' perception. The procedure will follow the method of constant stimuli with a two-alternative forced choice (2AFC) paradigm [6]. To do so, we envision a weight discrimination task in VR in which users need to lift two visually identical virtual boxes and choose the heavier one. One of the two boxes would always be haptically displayed with the same trigger resistance, the other box with different intensities from a predetermined set. By measuring the proportions of “heavier”-responses for each tested resistance, the JND can be calculated for each user as well as insights gained regarding the effect of the resistance intensity on the perceived weight. The possible setup for the task in the VE is illustrated in Figure 4. Findings will identify advantages and limitations from a perceptual and hardware perspective and, therefore, offer important insights for augmenting the trigger in commercial VR controllers with haptic feedback.

In the future, designing triggers with adaptive resistance could be one way to equip VR controllers with enriched haptic feedback. Since the trigger is a commonly used button that can be found in other VR controllers such as Oculus Touch or game controllers, actuated triggers could be integrated into a variety of interaction devices. In addition, we want to expand the scope of application for the adaptive trigger in VR beyond weight perception by exploring other physical properties such as stiffness, or haptic feedback for virtual user interface (UI) elements. Further, we envision other input components available in commercial VR controllers such as the thumbstick or trackpad to support different types of haptic feedback. Since these components also support different interaction techniques, they could support haptic feedback specifically rendered towards a particular user input, e.g., a push of a particular button or trackpad.

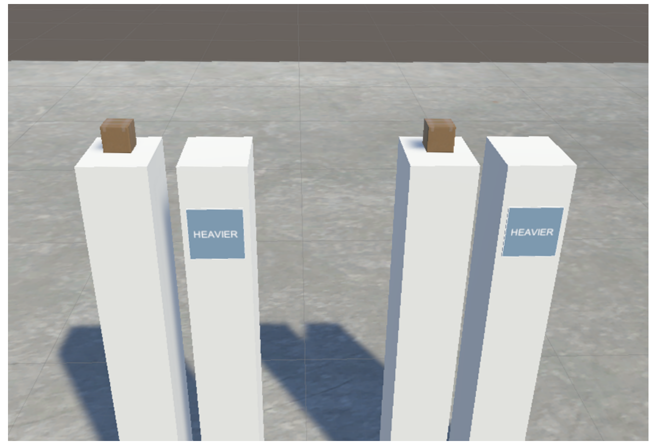

Figure 4: Possible setup in the VE for a planned user study. Both boxes should be lifted and placed onto the platform right next to it. A virtual ”HEAVIER”-button on each target platform allows participants to log in their response of which box they experienced heavier. The buttons do not indicate which box was haptically rendered heavier.

5 Conclusion

In this workshop paper, we presented a new approach to enable haptic feedback in commercial VR controllers by augmenting the trigger with adaptive resistance. We presented our hand-held controller *Triggermuscle*, which was built as a proof of concept to simulate the weight of virtual objects. Triggermuscle dynamically adapts the resistance of the trigger according to the weight of a grabbed virtual object. Users, therefore, need to scale their applied index finger forces to grab different virtual weights: The heavier the virtual object, the more force needs to be applied to pull the trigger. A demonstration video of the working prototype will be presented during the workshop. Future steps for the evaluation of the adaptive trigger were discussed as well as possibilities to extend the scope of application of haptic-enabled buttons. We hope that this work motivates further research on transforming established input elements into input-output components to enhance the haptic experience with commercial hand-held VR controllers.

References

[1] H. Benko, C. Holz, M. Sinclair, and E. Ofek. NormalTouch and TextureTouch: High-Fidelity 3D Haptic Shape Rendering on Handheld Virtual Reality Controllers. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, UIST '16, pp. 717–728. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2984511.2984526

[2] C. H. Cheng, C. C. Chang, Y. H. Chen, Y. L. Lin, J. Y. Huang, P. H. Han, J. C. Ko, and L. C. Lee. GravityCup: A Liquid-Based Haptics for Simulating Dynamic Weight in Virtual Reality. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*, VRST '18, pp. 1–2. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3281505.3281569

[3] I. Choi, H. Culbertson, M. R. Miller, A. Olwal, and S. Follmer. Grabity: A Wearable Haptic Interface for Simulating Weight and Grasping in Virtual Reality. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*, UIST '17, pp. 119–130. Association for Computing Machinery, New York, NY, USA, 2017. doi: 10.1145/3126594.3126599

[4] I. Choi, E. Ofek, H. Benko, M. Sinclair, and C. Holz. CLAW: A Multifunctional Handheld Haptic Controller for Grasping, Touching, and Triggering in Virtual Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pp. 1–13. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3173574.3174228

[5] L. Dominjon, A. Lécuyer, J. M. Burkhardt, P. Richard, and S. Richir. Influence of Control/Display Ratio on the Perception of Mass of Manipulated Objects in Virtual Environments. In *Proceedings of the 2005 IEEE Conference 2005 on Virtual Reality*, VR '05, pp. 19–25. IEEE, 2005. doi: 10.1109/VR.2005.49

[6] L. A. Jones and H. Z. Tan. Application of Psychophysical Techniques to Haptic Research. *IEEE Transactions on Haptics*, 6(3):268–284, 2013. doi: 10.1109/TOH.2012.74

[7] K. A. Kaczmarek, J. G. Webster, P. Bach-y Rita, and W. J. Tompkins. Electrotactile and Vibrotactile Displays for Sensory Substitution Systems. *IEEE Transactions on Biomedical Engineering*, 38(1):1–16, 1991. doi: 10.1109/10.6820

[8] J. Lee, M. Sinclair, M. Gonzalez-Franco, E. Ofek, and C. Holz. TORC: A Virtual Reality Controller for In-Hand High-Dexterity Finger Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, pp. 1–13. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3290605.3300301

[9] Y. Liu, T. Hashimoto, S. Yoshida, T. Narumi, T. Tanikawa, and M. Hirose. ShapeSense: A 2D Shape Rendering VR Device with Moving Surfaces That Controls Mass Properties and Air Resistance. In *ACM SIGGRAPH 2019 Emerging Technologies*, SIGGRAPH '19, pp. 1–2. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3305367.3327991

[10] P. Lopes, S. You, L. P. Cheng, S. Marwecki, and P. Baudisch. Providing Haptics to Walls & Heavy Objects in Virtual Reality by Means of Electrical Muscle Stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, pp. 1471–1482. Association for Computing Machinery, New York, NY, USA, 2017. doi: 10.1145/3025453.3025600

[11] K. Minamizawa, S. Fukamachi, H. Kajimoto, N. Kawakami, and S. Tachi. Gravity Grabber: Wearable Haptic Display to Present Virtual Mass Sensation. In *ACM SIGGRAPH 2007 Emerging Technologies*, SIGGRAPH '07, pp. 3–6. Association for Computing Machinery, New York, NY, USA, 2007. doi: 10.1145/1278280.1278289

[12] M. Parmar. Multiple Microsoft patents point to Xbox One controller improvements. https://www.windowslatest.com/2019/01/02/multiple-new-microsoft-patents-for-xbox-one-controller/. (accessed 18 June 2020).

[13] PlayStation. DualSense wireless controller: The innovative new controller for PS5. https://www.playstation.com/en-gb/accessories/dualsense-wireless-controller/. (accessed 4 September 2020).

[14] N. Ryu, W. Lee, M. J. Kim, and A. Bianchi. ElaStick: A Handheld Variable Stiffness Display for Rendering Dynamic Haptic Response of Flexible Object. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, UIST '20. Association for Computing Machinery, 2020. doi: 10.1145/3379337.3415862

[15] J. Shigeyama, T. Narumi, T. Hashimoto, T. Tanikawa, S. Yoshida, and M. Hirose. Transcalibur: A Weight Shifting Virtual Reality Controller for 2D Shape Rendering Based on Computational Perception Model. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, pp. 1–11. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3290605.3300241

[16] M. Sinclair, E. Ofek, M. Gonzalez-Franco, and C. Holz. CapstanCrunch: A Haptic VR Controller with User-Supplied Force Feedback. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*, UIST '19, pp. 815–829. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3332165.3347891

[17] J. M. Suchoski, S. Martinez, and A. M. Okamura. Scaling inertial forces to alter weight perception in virtual reality. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 484–489. IEEE, 2018.

[18] G. Westling and R. S. Johansson. Factors Influencing the Force Control During Precision Grip. *Experimental Brain Research*, 53(2):277–284, 1984. doi: 10.1007/BF00238156

[19] E. Whitmire, H. Benko, C. Holz, E. Ofek, and M. Sinclair. Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pp. 1–12. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3173574.3173660

[20] A. Zenner and A. Krüger. Shifty: A Weight-Shifting Dynamic Passive Haptic Proxy to Enhance Object Perception in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics*, 23(4):1285–1294, April 2017. doi: 10.1109/TVCG.2017.2656978

[21] A. Zenner and A. Krüger. Drag:on: A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, pp. 1–12. Association for Computing Machinery, New York, NY, USA, may 2019. doi: 10.1145/3290605.3300441