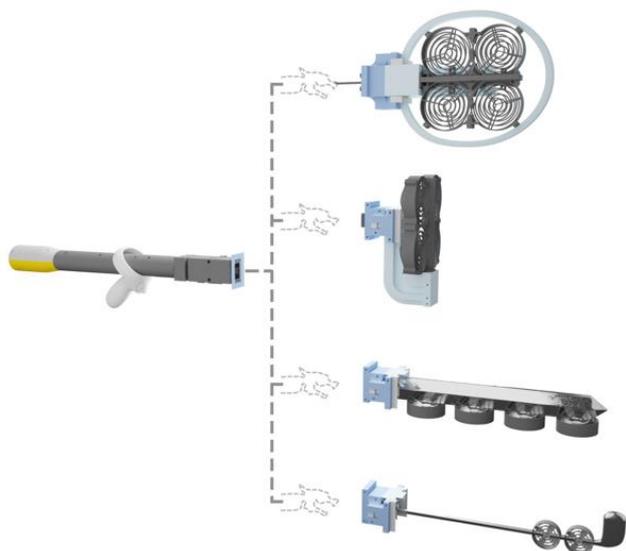


SA/MA: Developing a Hybrid Controller for Multi-Haptic Feedback to Mimic Impulsive Forces in Virtual Reality

We want to develop a versatile Virtual Reality (VR) controller to create haptic illusions for impulsive force scenarios. For that, an active haptic device is essential. The HYbriD contRoller for multi-hAptic feedback (HYDRA) combines force feedback based on airflow with instantaneous tactile feedback realized through a magnetically accelerated weight.



We further experimented on technology to address challenges in the application of brushless motors for force feedback, specifically toroidal propellers in conjunction with options to adjust the motor layout. In the next steps, we want to refine the HYDRA concept. This includes measuring real impulsive forces and then specifically recreating them with HYDRA inside of a VR simulation (Unity-based). This will be done based on sports applications. Another aspect we want to refine is the use of specific toroidal propeller designs. At last, HYDRA allows the development of

different force feedback layouts. We want to experiment with such layouts to maximize its applicability in VR simulations. Additionally, we want to further include the idea of dynamic, potentially AI-based haptics.

Requirements/Skills: Highly motivated with an independent work approach, programming skills(C++, Python), ideally 3D-printing expertise, and basic electronics knowledge.

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Additional Information: Poster-presentation

HYDRA – A Hybrid Controller for Multi-Haptic Feedback to Mimic Impulsive Forces in Virtual Reality

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Figure 1: (A) Player using HYDRA in Virtual Reality; (B) Description of the force and tactile feedback felt and their effects; (C) The multi-haptic illusion brought to life by defending against attackers; (D) Role-Playing Game scenario made with Unity.

ABSTRACT

In this project, we envision a versatile Virtual Reality (VR) controller to create haptic illusions for impulsive force scenarios where an active haptic device is essential. The HYBRID controller for multi-haptic feedback (HYDRA) combines force feedback based on airflow with instantaneous tactile feedback realized through a magnetically accelerated weight. To address challenges in the application of brushless motors for force feedback, we propose using toroidal propellers in conjunction with options to adjust the motor layout. For an early pilot study, a Role-Playing Game (RPG) scenario was developed, where, based on a haptic illusion, HYDRA mimicked a 16th-century matchlock musket. With 24 participants, the potential of HYDRA was visible in terms of usability and presence response, as well as promising directions for future studies examining the influence of both feedback types on the experience.

Index Terms: Multi-Haptic, Haptics, Force Feedback, Tactile Feedback, Virtual Reality, Controller, Impulsive Forces.

1 INTRODUCTION

Multi-haptic approaches are less commonly utilized to create haptic stimuli in VR, yet they offer potential through a seamless and spatially overlaid experience [5]. Moreover, multi-haptics have been experimented with, such as within cave setups or expressive sports simulations [4]. The question arises: Can this potential be utilized in a modular, multi-haptic VR controller?

Because a "perfect multi-sensory display" [3] is not feasible (yet), special-purpose tools are designed to replace standard VR controllers with, e.g., vibrotactile cues or force feedback [2].

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Action-driven scenarios rely on impulsive forces, where a burst of force is felt and affects the player, e.g., a ball being hit with a bat [4].

We envision a HYBRID controller for multi-haptic feedback (HYDRA), which has adjustable force feedback (the "heads" of the HYDRA) based on the layout of brushless motors combined with instantaneous tactile feedback based on solenoids (see Figure 1 (B)). To mitigate some of the challenges associated with the force feedback approach, e.g., noise, custom toroidal propellers [1] have been incorporated. Additionally, we propose the use of solenoids for controllable and instantaneous impact sensations through a spring-based mechanism. For a pilot study, we incorporated HYDRA into a VR RPG and conducted a pilot study (see Figure 1 (A), (C), (D)). We aim to spark interest in combining force and tactile feedback in handheld controllers to enable simulated tool feedback and increased authenticity. Our contributions are:

- The design of HYDRA, a tube-shaped multi-haptic VR controller that offers precision in mimicking impulsive forces by combining force and instantaneous tactile feedback.
- The novel use of toroidal propellers combined with swapping the motor layout to increase adaptability for impulsive forces.

2 IMPLEMENTATION

HYDRA with a vertical force feedback layout has a length of 641 mm, a width of 162.5 mm, and a height of 222 mm.

2.1 Force Feedback - Toroidal Propellers

HYDRA is incorporating flexible force feedback directions, as depicted with Thor's Hammer [2], combined with tactile feedback to enhance the experience through a multi-haptic approach. Our detachable force feedback layout functions through a joint inspired by Japanese Joinery and spring-loaded pins (see Figure 2). The four motors offer a fast spin-up time and achieve nearly 1 kg of thrust combined with reliable repeatability. To reduce the noise and enhance airflow, we experimented with 3-bladed drone propellers and

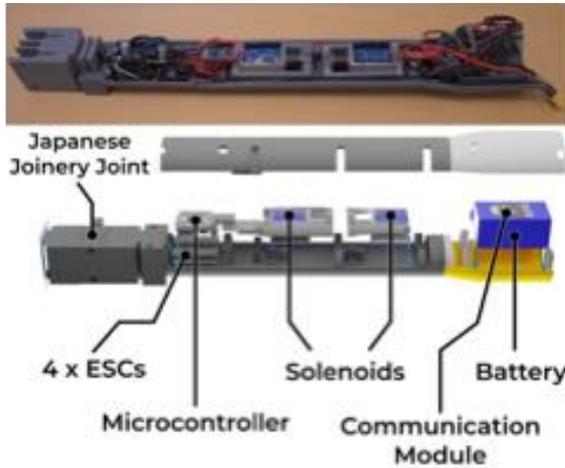


Figure 2: Microelectronics (Top: Physical world, Bottom: CAD model): (Left) connector with pins to attach force feedback layouts (motors and propellers); (Central) ESCs and solenoids with spring-based mechanism; (Right) communication/energy management.

8- or 12-bladed 3D-printed toroidal propellers (see Figure 3). The propellers are printed in Acrylonitrile-Styrene-Acrylate (ASA), a durable and vapor-smoothable material. We measured the velocity and noise generated by the propellers for 30 seconds at a 10-cm distance using a coplanar-mounted anemometer (TopTes TS-301) and a sound level meter (Voltcraft MT 52) at a 1-meter distance. This was repeated three times for each propeller, and the mean of the maximum measurements was taken. The “Toroidal 8 Blades 20 degree” offers a balance between airflow (9.09 m/s) and noise (98 dBc), outperforming traditional propellers (Gemfan 3028 3x2.8 WinDancer, 8.6 m/s with 103 dB). Noise at a 1kHz frequency is typically generated, producing mental stress. Toroidal propellers distribute sound energy across a broader frequency band. Upgrading to a larger frame allows us to utilize 4- to 6-inch propeller designs.

2.2 Tactile Feedback - Solenoids

Traditional VR controllers are equipped with rumble motors, a heavy-duty variant of vibration motors. However, they fall short in sensation (unnatural feeling), limited flexibility to simulate a variety of interactions, and react slowly to in-game situations based on linear mass accelerations. In previous research, solenoids have been envisioned as a means to generate compelling feedback, e.g., simulating force and torque impacts in sports. HYDRA offers precise and instantaneous vibration feedback based on two solenoids (TDS-10A, 8 mm, 12V). Thereby, 26 N of force is generated through 90 g of weight propelled as a projectile, which travels 8 mm, impacting a reinforced wall at 2 m/s. The impact occurs precisely in 25 ms, and per solenoid, this would equal 0.18 J of kinetic energy. We attached the rod of the solenoids to the handle while the metal cage and the coil moved along it freely. A spring pushes the coil back. The axes of the two solenoids point in opposite directions to generate three types of impact: upward, downward, and stationary.

3 PILOT STUDY

The player is represented as an adventurer of the Renaissance. A first-person perspective, hand tracking, and being able to move on the spot are used. HYDRA will mimic firing a heavy 16th-century matchlock musket to defend against attackers. This involves an orchestrated combination of tactile feedback by initiating the trigger

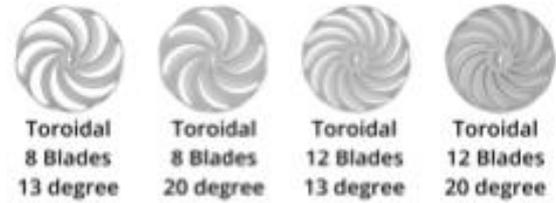


Figure 3: CAD designs of four tested toroidal propellers.

(two solenoids: one towards the player and one in the opposite direction) and force feedback, the recoil felt (brushless motors) firing the lead ball. After pushing the trigger, roughly 20 ms later, the signal is received by HYDRA, triggering the solenoids and the motors. The motors have an estimated 5 ms spin-up time with some delay until perceiving the force feedback (in total, ~45 ms). After the perceived “click”, the force feedback will be felt for another 400 ms by spinning the motors. The propulsion of the lead ball can be considered a “compelling contact force”, which needs to be mediated to the user (tactile and force feedback). This illusion is reinforced by the firing sequence being vividly visualized.

There were 24 participants (computer science students), of whom 14 were male, and 10 were female, between the ages of 18 and 34 years. In terms of experiencing VR before, 45.8% of the participants had played VR games once, 33.3% had never played before, and 20.8% had played regularly. They described their experience with HYDRA as “perceiving powerful forces”, although HYDRA has a limited push-back force. The shape depicting a rifle was not a significant factor in this feeling, but force and tactile feedback were. Additionally, there were differences in weight perception: some perceived it as comfortable and authentic (71%), while others would prefer a lighter controller (29%). We observed positive results for usability based on the System Usability Scale with a score of 84-90. Based on using the Igroup Presence Questionnaire, for PRES, a score of 5.31 was recorded.

4 FUTURE WORK

Further research will be necessary to understand which part of the forces, in combination with the type, is influential on an experience with multi-haptic feedback. This leads to both technical evaluations and empirical studies, where we aim to further explore how to optimize force and tactile feedback. Emphasis will be placed on the toroidal propellers as well as different force feedback layouts.

5 CONCLUSION

HYDRA allows recreating authentic impulsive forces, with initial promising usability and presence scores. Based on creating such vivid haptic illusions, users may react as if they would in the physical world, even if they did not experience the events before.

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