Haptic-go-round: A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences

Hsin-Yu Huang*, Chih-Wei Ning*, Po-Yao (Cosmos) Wang, Jen-Hao Cheng, Lung-Pan Cheng
Department of Computer Science and Information Engineering
National Taiwan University, Taipei, Taiwan
{first-name}.{last-name}@hci.csie.ntu.edu.tw

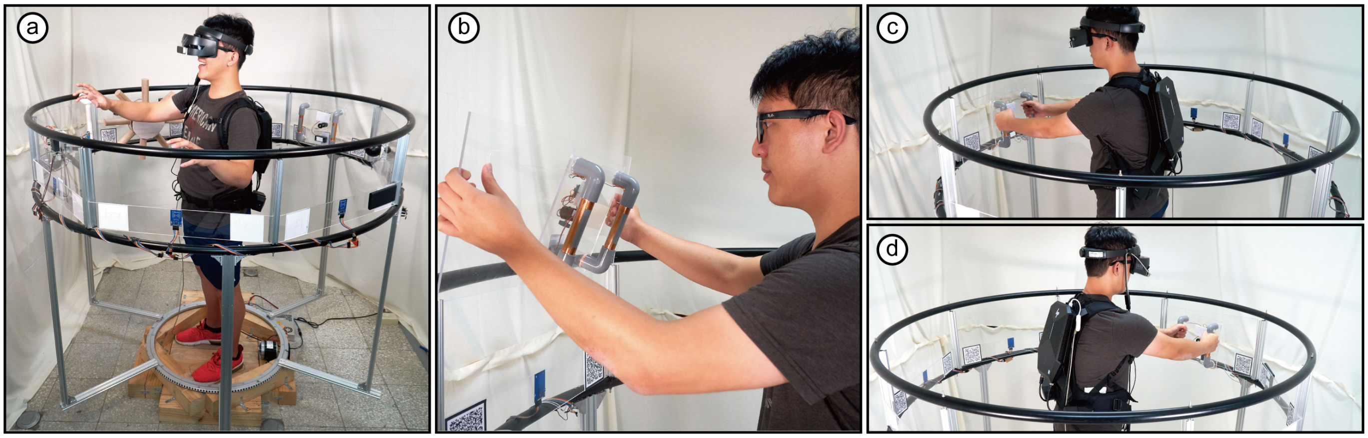

Figure 1. (a) Haptic-go-round is a platform that allows a user to feel haptic feedback when interacting with objects in virtual reality in any direction. (b) Haptic-go-round enables agile deployment of encounter-type haptics. Users reconfigure haptic components on the platform freely for their applications by sliding in or out *prop cartridges* where props or devices are attached. (c) Haptic-go-round automatically registers the haptic components and rotates to the right position when the user is about to touch the corresponding virtual objects in the virtual world. (d) Here shows a classic example of encounter-type haptics where the newly added haptic component is reused for another virtual object in a different direction.

ABSTRACT

We present Haptic-go-round, a surrounding platform that allows deploying props and devices to provide haptic feedbacks in any direction in virtual reality experiences. The key component of Haptic-go-round is a motorized turntable that rotates the correct haptic device to the right direction at the right time to match what users are about to touch. We implemented a working platform including plug-and-play prop cartridges and a software interface that allow experience designers to agilely add their haptic components and use the platform for their applications. We conducted technical experiments and two user studies on Haptic-go-round to evaluate its performance. We report the results and discuss our insights and limitations.

Author Keywords

Encounter-type haptic feedback; props; virtual reality.

CCS Concepts

•**Human-centered computing → Haptic devices;**

INTRODUCTION

Since the invention of the head-mounted display in 1968 [30], researchers have sought to enhance immersion by photorealistic graphics, spatial sound and motion capturing. As these technologies become mature, many researchers have shifted the focus towards the next level of immersion where users not only see and hear, but also feel virtual worlds [29].

Several approaches revolve around employing specific equipment such as PHANToM [22], exoskeletons [6, 32], electrical muscle stimulation [21], shape displays [15, 19] or passive props [10, 24] to simulate specific types of haptic feedback (e.g., force or tactile) in virtual reality (VR). To provide more general haptic feedback in VR, researchers have proposed proxy-based and encounter-type haptics where robots [3, 23] or humans [11, 9] carry the right equipment to the right position to match what users are about to feel in the virtual world. While these approaches ensure maximum degrees of freedom (DOF), they come at prices: (1) switching equipment is inefficient as each actuator only carries one at a time; (2) adding additional actuators costs much and requires more space to avoid collision. These raise the bar of using encounter-type haptics in virtual experiencesf.

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*Both authors contributed equally to this research.

CHI '20, April 25–30, 2020, Honolulu, HI, USA.

ACM ISBN 978-1-4503-6708-0/20/04 ...$15.00.
http://dx.doi.org/10.1145/3313831.3376476

In this paper, we bring encounter-type haptics in VR to a more pragmatic level using a single actuator to carry multiple haptic components around a user. We propose Haptic-go-round, a merry-go-round-like platform (Figure 1a) for agile deployment of encounter-type haptics in virtual experiences.

Deploying Encounter-type Haptics with Haptic-go-round

We demonstrate Haptic-go-round by walking through our development of an immersive warship game that involves haptic feedback.

We start by constructing the virtual scene: a warship floating on water. We add a steering wheel and a throttle next to it for sailing the ship to a destination. As shown in Figure 2a, the software interface of Haptic-go-round displays a highlighted ring to indicate the effective region for placing interactive virtual objects. Anywhere on the region is valid for Haptic-go-round. We choose a favorable position in front of the ship.

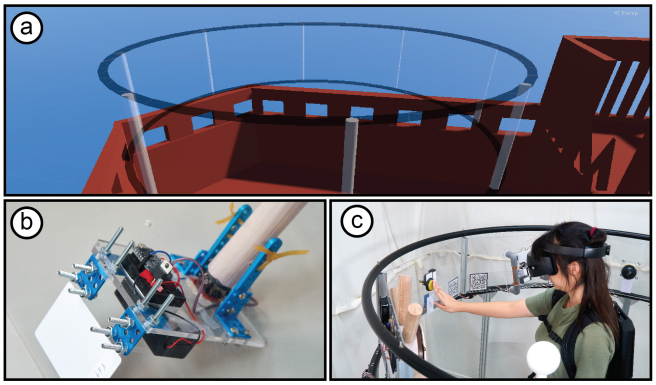

Figure 2. (a) The software interface of Haptic-go-round shows its ring frame in the editor view as the effective region for placing interactive virtual objects. (b) The user attaches a haptic component, here a lever, to the flat prop cartridges using screws. (c) The user clicks the start button on Haptic-go-round to start the calibration process.

Next, we make a steering wheel and a lever prop and attach them to prop cartridges. The prop cartridge is a flat surface so most of the attachment tools such as screws and glue work. Here we use screws (Figure 2b). We insert the prop cartridges to the adjacent slots on Haptic-go-round. Haptic-go-round identifies the RFID tags on the cartridges and registers with their slot numbers.

To conduct a unit test, we equip our VR system and stand in the center of the platform . By clicking the start button (Figure 2c), Haptic-go-round automatically calibrates with the VR system and rotates to the right position where the props and the virtual objects are matched. We then control the virtual ship by really manipulating the steering wheel and the throttle.

To bring bifurcation into the game experience, we add a telescope onto the ship for checking which destination to go. We make a spade grip that is attached to a ball joint as the handle of the telescope as shown in Figure 1b. Since the use of telescope is independent from the use of the steering wheel, we put the spade grip cartridge in an arbitrary empty slot without taking care of the relative position and let Haptic-go-round to take care of positioning (Figure 1c).

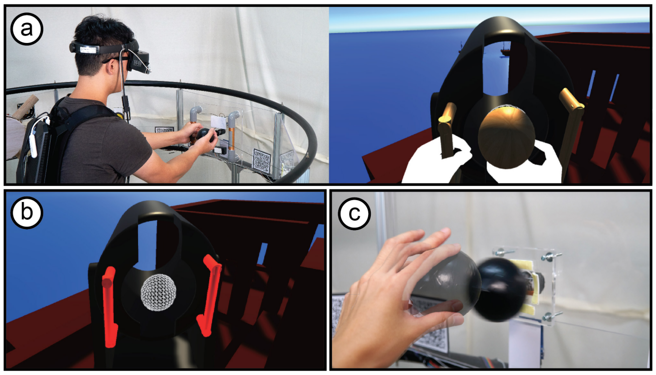

Figure 3. (a) The user grabs the cannonball prop and put it in front of the spade grip to fire. (b) Haptic-go-round shows a highlighted red contour around the virtual object to indicate that it is not in position yet. (c) The cannonball retracts back to its original place after the user releasing it.

To spice up the cruise, we add a cannon for shooting enemy fleet down. This time we reuse the same spade grip prop as the telescope since they use the same mechanism. The only thing we do is to register the virtual cannon with the spade grip prop in the software interface.

If the prop is not ready, Haptic-go-round notifies the application and highlights the contour of the virtual object to warn the user as shown in Figure 3b.

We add a cannonball prop next to the spade grip for the user to load the cannon. The user fires the cannonball by dragging the cannonball prop to the middle of the spade grip as shown in Figure 3a. The cannonball prop has a retracting mechanism to bring the cannonball back in place (Figure 3c). This allows the user to reuse the cannonball prop to fire multiple times.

Figure 4. The user is dragged by Haptic-go-round from one direction to another while fishing in the virtual scene.

Finally, we add an intensive interaction: fishing. We tie an elastic rope to a VR controller and latch the other end to a prop cartridge. As shown in Figure 4, Haptic-go-round also provides force feedback when the user is dragged by a virtual marlin around the ship.

More Example Applications

We show more examples of incorporating Haptic-go-round with other existed game genres in Figure 5. Figure 5a shows our first person shooter game. We mount a Nerf gun onto Haptic-go-round to simulate enemies shoot around the user. Figure 5b shows our 360-degree rhythm game. The notes arrive around the user from arbitrary directions. The user clicks the button at the right position at the right time to score. We mount multiple same type of buttons as redundant components to shorten Haptic-go-round's traveling distance and time. Figure 5c shows our room escaping game. The user grabs an electric plug and a socket in each of his hands and connects them to open the door. The surrounding platform enables large-scale bimanual interactions 180 degrees across the platform.

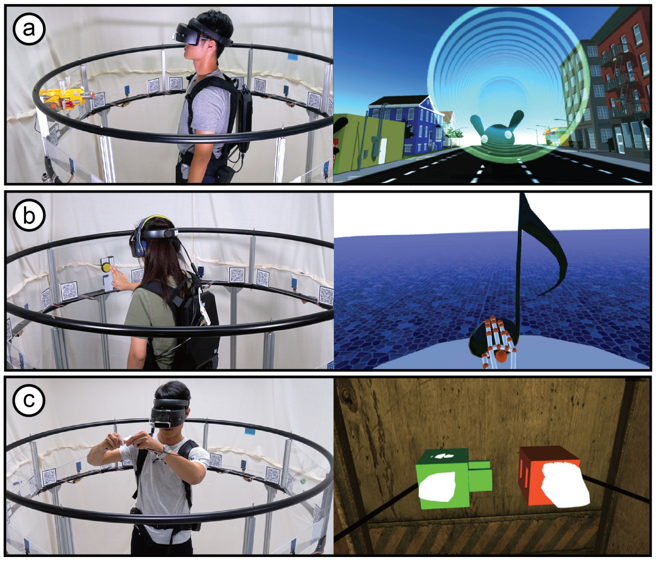

Figure 5. (a)Mounted with a Nerf gun, Haptic-go-round strikes the user from any direction in a first person shooter game. (b) Mounted with multiple same type of buttons for shorter response time, Haptic-go-round enables a 360-degree rhythm game. (c) Mounted with a plug and a socket on the opposite side, Haptic-go-round allows 180-degree bimanual interactions in a room escaping game.

We summarize all functionalities of Haptic-go-round that we have demonstrated as encounter-type haptics: (1) positioning haptic components to provide matching haptic feedback in VR; (2) reusing one haptic component for many virtual objects; (3) adding redundant haptic components to speed up response time; (4) using movement to provide force feedback.

Contributions

The main contribution of this paper is the platform along with its software interface. Our key idea is, unlike classic encounter-type haptics that use multiple high DOF actuators to carry one equipment at a time, Haptic-go-round uses only one 1-DOF actuator to carry multiple haptic components around the user. This approach bypasses complex path planning and picking problems in robotics, eliminates the need of estimating the number of required actuators and thus lowers the bar of employing encounter-type haptics in existed or new virtual reality experiences. Together with the plug-and-play prop cartridges and the software mapping interface, Haptic-go-round enables agile deployment of props and devices to be a part of encounter-type haptics in VR. We detail our design considerations and implementation along with technical evaluation results as a specification for further use.

We see Haptic-go-round as a new type of arcade machines that works with 360 immersive experiences in contrast to current machines that only allow users to manipulate one prop or device at all time in one direction. Since current VR systems have not yet been ready for walking in uncontrolled spaces, most of current VR experiences were developed for stationary use but involved turning around and object manipulation to enhance immersion. Haptic-go-round is thus aiming for bringing haptic feedback into this type of experiences in an arcade set-up to enhance immersion.

RELATED WORK

This work relates to research on (1) encounter-type haptics, (2) proxies and props for VR and (3) immersive spaces.

Encounter-type Haptics

The concept of encounter-type haptics originated from Robotic Graphics [23] in which a robotic arm positions a board to provide matching touch feedback when the user touches a virtual object. Yokokohji et al. coined encounter-type display in WYSIWYF Display [35] as the user "encounter" the display only when touching a virtual object. Researchers have extended the concept in several directions. Human actuation [8, 9, 11] uses humans instead of machines to implement encounter-type haptics. Snake Charmer [3] replaces end effectors on a robotic arm to provide more haptic feedback such as texture or temperature rather than shape. shapeShifter [27] uses an omni-directional robot to carry a shape display consisting of motorized pins to match the virtual geometry wherever the user is touching. NormalTouch [5], Haptic Revovler [33] and RollingStone [20] make VR handheld controllers to provide encounter-type haptic feedback by changing shape, texture and dragging underneath a finger. Recent researches have proposed using drones [1, 2] as encounter-type haptic interfaces so as to simulate grounded haptic feedback while achieving mobility and hands-free interactions. While Haptic-go-round is inspired by these works especially in its circular form factor, it aims for enabling agile deployment of props as encounter-type haptics.

Proxies and Props for VR

Hinckley et al. [16] pioneered using a passive prop as a proxy to provide haptic feedback while controlling 3D virtual models, followed by Bricks [14]– a foundation of tangible interfaces [18]. Insko [17] concluded that passive props significantly enhances virtual environments from his studies. More recent researches have employed props in various forms for immersive VR experiences. Ortega et al. [24] proposed prop-based haptic interaction in a VR automotive design application. Sparse Haptic Proxy [10] uses a hemispherical prop along with the Haptic Retargeting technique [4] as a proxy for physically touching virtual objects.

In contrast to static passive props, researchers have proposed dynamic passive props that are mixed with mechanisms or small active components to enrich expressiveness.

TurkDeck [11] uses a set of reconfigurable boards to represent various objects in the virtual scene. iTurk [8] uses a pendulum prop to redirect energy back and hit the user. HapTwist [37] consists of multiple sections sticks that can be twisted to match a virtual object. Shifty [36], Transcalibur [26] and PuPop [31] adds mechanical or pneumatical actuators to change the states of the props to represent more virtual objects than just the default state. As the variety of VR props increases, Haptic-go-round provides a good mounting base for the user to switch between multiple props on demand in virtual experiences.

Immersive Spaces

Traditionally, a tracking space (e.g., a fixed empty room instrumented with professional cameras and displays) is required to bring a user's body into the virtual world. The CAVE [12], for example, uses 6 projected walls to surround and include the user's body in the virtual world. To save the use of the space, researchers have proposed redirected walking [25], impossible spaces [28], and the omni-treadmill [13] to make users circle around a room or walk in place. While current VR headsets have employed inside-out tracking, several issues such as maintaining narrative in the virtual world are still in research stage [7, 34] when it comes to uncontrolled spaces. We see a synergy between Haptic-go-round and omni-treadmill and maintain the capability of using inside-out tracking to reduce the instrumentation effort.

DESIGNING & BUILDING HAPTIC-GO-ROUND

We describe our design considerations and implementation details in this section.

Design Considerations

Shape: To ensure stability when rotating and to keep the same distance to the user, we set the shape of the platform to be a uniform ring.

Height: Since most of current virtual experiences are designed for stationary standing, we set the height of the platform to be at the average chest level (140 cm).

Width: To prevent the user from unintentional collision with the frame while maintaining reachability, we set the width of the platform to be a little larger than the average armspan (165 cm).

Degrees of freedom: One of our primary goals is to reduce the complexity of using encounter-type haptics. We thus chose to use one actuator without adding extra degrees of freedom, i.e., an additional ring frame that spins independently.

Angular resolution: While it is possible to have higher angular resolution using high frequency micro controller units and encoders, we chose 1 degree to be our angular resolution since the error within can be compensated by Haptic Retargeting technique [4].

Maximum Load: As most of current props for VR are light weight, we set the maximum load to be 10 kg. We set the maximum number of props to be adjustable. We chose 8 for our examples.

Speed & Safety: To ensure safety while maintaining performance, we set the maximum speed to be at 500 rpm.

Hardware

Based on our design considerations, we built the Haptic-go-round platform. Figure 6 shows an overview of the platform. The ring frame consists of two 165-cm Cyr wheels and 8 of 30-cm aluminum profiles that rigidly link two wheels and create 8 of cartridge slots. The ring frame is supported by 6 of 40.5-cm aluminum profiles that are rigidly linked with a 80-cm-wide turntable in the center. The height from the bottom of the platform to the center of the ring frame is 140 cm as our design. The turntable is friction-driven by a motor used for electric bike (MY1016, 350 watts, 36 volt, 2800 Rpm) as shown in Figure 6b. The turntable and motor could be replaced by an off-the-shelf electric rotating platform while we did not find one with such power.

Two infrared sensors and printed black and white stripes (0.7 cm wide) around the circumference of the outer ring of the turntable are used as A-B incremental rotary encoder as shown in Figure 6c. Two infrared sensors are shifted half of the phase from each other and the mounts of the sensors are laser cut accordingly. A complete white stripe is added in the end to reset the counter to 0.

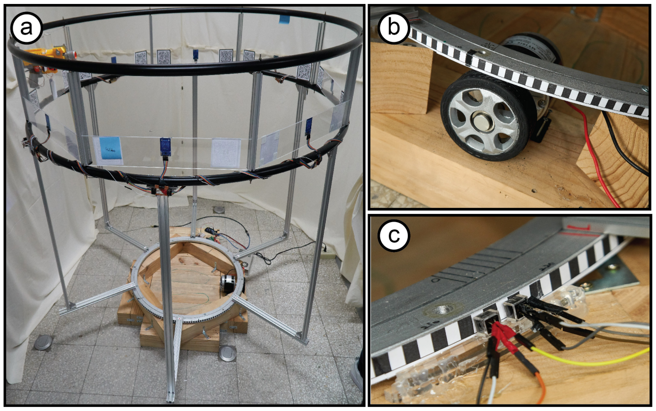

Figure 6. (a) An overview of the platform. (b) The turntable is friction-driven by a DC motor. (c) The incremental encoder consists of two displaced infrared sensors reading the black-and-white pattern attached to the turntable.

Control System

A micro controller unit (Arduino Mega 2560) is used to control the platform. A motor driver board (AQMS3615NS) is used to control the power and direction of the motor. We used PID control ($k_p = 10$, $k_i = 0.01$, $k_d = 0.2$ for acute angle; $k_p = 15$, $k_i = 0.01$, $k_d = 0.83$ for obtuse angle) to control the rotation of the motor. We empirically tested the working range of the PWM and found the minimum duty cycle is 30 to reach our target RPM from our design considerations. We linearly map the PID value to the PWM value to the offset range. The micro controller unit connects to a computer and use wireless network to communicate with our software system.

Prop Cartridges

To allow agile reconfiguration and customization, Haptic-go-round employs cartridges. A prop cartridge is made of a 5 mm transparent acrylic sheet with an RFID tag for identification (Figure 2b). The flat surface allows most of the attachment tools such as screws and glue for users to work with. The transparency of the prop cartridge ensures inside-out tracking works from the center of the platform. Since our maximum number of slots is 8, each of the cartridge is 30 cm in height and 62 cm in width.

We assume that the the center of the prop is mounted on the center of the cartridge. Otherwise, users have to manually adjust the offset in the software interface to match the exact position.

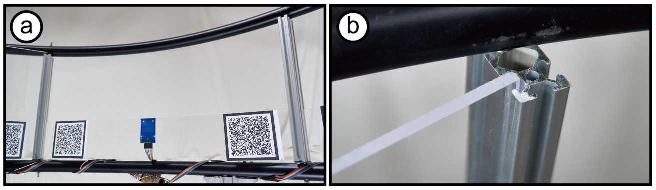

Figure 7. (a) A slot of a prop cartridge includes two aluminum profiles, two markers for calibration and a RFID reader for identification. (b) 5 mm acrylic sheet could be easily inserted into the notch of the aluminum profiles.

A prop cartridge can be slid into a slot on the platform (Figure 7). On the back of each cartridge slot, there are a RFID reader (MFRC522) which is used to read the RFID tag of each cartridge and two printed markers for calibrating the inside-out tracking and the platform. The RFID readers are connected to two micro controller units (Node MCU Ver0.1) and wirelessly communicate with our software system to register the prop positions.

Some props (e.g., steering wheel) in our example applications have a WeMos D1 mini board to receive trigger event. These can also be replaced by mixed reality controller as we shown in 4. While making props is beyond the scope of this paper, we used rotary encoders, force sensors etc., to track the props status and trigger events in our applications.

Software System

Figure 8 shows our complete system diagram. In our demo applications, we used a HP backpack PC and a HP windows mixed reality headset. We attached a leap motion in front of the headset to track users' hands. We developed our example applications in Unity.

The software interface is written in C# and can be integrated in Unity. The software interface (1) displays the 3D model of Haptic-go-round as an indicator for experience designers to place the virtual object in the effective region (Figure 2a) , (2) manages the mappings between each prop cartridge and virtual object and (3) coordinates applications, the control and the cartridge systems. Once a cartridge is attached/dettached to/from the platform, the software interface receives the RFID tag number read from the reader. Users put in the RFID tag number in the ID field of the virtual object to create the mapping. The software interface calculates the target rotation angle using the offset between the angular coordinates of the virtual object and the corresponding prop cartridge. The software interface does not manage the use of props. In other words, applications are responsible for managing prop interactions such as animating a button being pressed.

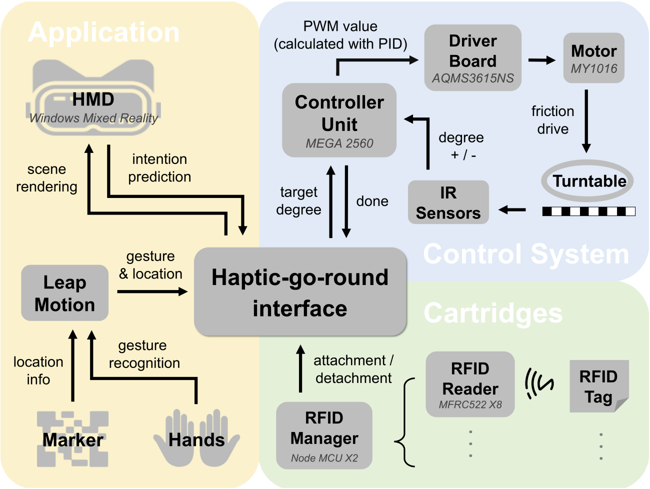

Figure 8. The architecture of the Haptic-go-round software interface. It interfaces with the control system, the cartridges system and applications.

Timing and Offset

The key challenge, like all encounter-type haptic interfaces, is to get the components in place for users in time. To reduce the response time, the system predicts the next object that the user wants to interact with using the center of the field of view as the user's gaze to observe the hand-eye coordination. To reduce the position error, the system uses Haptic Retargeting [4] to compensate encoder error (< 1°) and optional pitch offset (< 15°) which is allowed for more flexible virtual level design.

TECHNICAL EVALUATION

To provide a technical specification for experience designers to use Haptic-go-round, we conducted an experiment to evaluate the response time (RT).

We define RT as the duration between the time when the controller unit receives the rotate command and the time when the motor completely stops. We set 18 target angles from 10-180°with 10-degree step. For each target angle, we sampled 10 times and calculated the average and the standard deviation while removing outliers. We tested with three loads: 0, 5 and 10 kg.

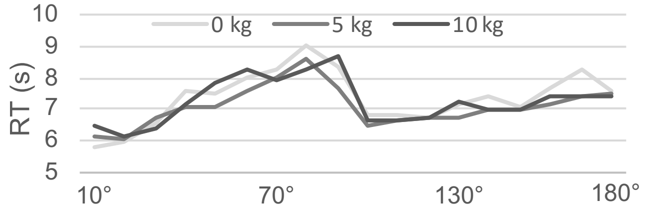

Figure 9. The response time for each target angle from 0°to 180°in 0, 5 and 10 kg loads.

Figure 9 shows the result. The average RT is 7.38 seconds ($SD = 0.96$) for acute angle and 7.11 seconds ($SD = 0.41$) for obtuse angle. Within each angle group, there is a positive correlation between RT and target angle. Such tendency suggests that, by installing redundant props in different slots on the platform, the expected latency could be systematically reduced since the maximum target angle would become smaller in that case. The result also shows that loading does not effectively affect RT in our case. The reason could be that our motor overwhelmed 10 kg.

STUDY 1: PRELIMINARY USER STUDY

The goal of this study is to validate the design of Haptic-go-round. Prior work has shown that incorrect haptic feedback reduces the realism in VR and leads to confusion. We thus compared Haptic-go-round with a baseline condition where no haptic feedback was presented.

Participants

We recruited 12 participants, 4 females, aged 21 to 23 ($M = 21.92$, $SD = 0.51$). 11 participants had experiences with VR, and 2 of them were VR experience developers. The height of the participants ranged from 161 cm to 182 cm.

Task and Procedure

We tested two conditions– Haptic-go-round and the baseline condition using within-subject design. In both conditions, each participant completes three tasks in our warship game experience: (1) shoot down the enemy ship by aiming with the telescope and firing the cannon; (2) drive the ship to a specific destination using the steering wheel and the lever throttle; (3) pull up the marlin swimming around the ship using the controller as the fishing rod.

We brought in one participant at a time. After a brief introduction and a 3-min training session, we guided the participant to the center of Haptic-go-round and started our warship game experience. The participant completed two conditions in counter-balanced order. After each condition, the participant was asked to rate the level of enjoyment and realism using 7-point Likert scale (1 = not at all and 7 = totally). Finally, the participant was interviewed briefly.

Result and Discussion

Figure 10 shows the results. Overall the participants felt more realistic with Haptic-go-round ($M = 4.67$, $SD = 0.99$ vs. $M = 3.75$, $SD = 1.14$, pairwise t-test, $t_{11} = 2.727$, $p = 0.010$). The effect on enjoyment is marginal ($M = 5.5$, $SD = 1.09$ vs. $M = 5$, $SD = 0.95$, $t_{11} = 1.732$, $p = 0.056$). 6 participants stated that having interaction with physical objects did increase realism. From our result, Haptic-go-round did provide realist haptic feedback that enhance virtual reality experience.

Among all the interactions in the experience, the "fishing" was the most favorable one. "Feeling force feedback from different directions was quite surprising", said P6. This supports our design decision of making a full-body scale platform.

P2 and P4 stated that using physical props increased the robustness of virtual object manipulation. "I no longer needed to worry that the hand tracking misunderstood my hand gestures", said P4.

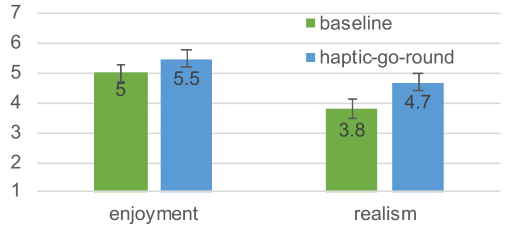

Figure 10. The ratings of enjoyment and realism. Comparing to the baseline condition, participants experienced more realism and enjoyment when using Haptic-go-round.

7 participants complained about the misalignment between the prop and virtual object. P5 said "When tracking lost happened, I had to guess whether I should trust what I saw or what I touched. It was quite confusing and interrupting." The misalignment could come from 3 sources: (1) encoder of the platform, (2) tracking of the props and (3) fabrication. While we have used haptic retargeting to correct encoder error, the misalignment could still come from improper tracking of the props and fabrication error. For example, our steering wheel did not give the rotation angle perfectly. Therefore, while the virtual wheel could align at the center, the position of each grip might still have some offset. This could be avoided by using more sophisticated sensing techniques and more careful calibration. As for the fabrication error, one could scan props and use 3D shape retargeting [37] to compensate.

STUDY 2: IN-DEPTH INTERVIEW WITH DESIGNERS

As the previous study focused on validating Haptic-go-round's usibility as a haptic device, we conducted the other study to evaluate it as a designing tool and gain insights into the development process.

Participants

We recruited 12 experience designers (4 females, aged 21 to 26, $M = 23.17$, $SD = 1.64$) who have more than 6 months experience. Among them 8 have worked with VR in which 7 have developed applications with haptic feedback.

Task and Procedure

We brought in one participant at a time. We introduced Haptic-go-round by showing our demo video to the participant and provided a hands-on walkthrough of working with the system. We then interviewed the participant in 2 major directions: (1) how they would integrate the system with their former projects and (2) how they would develop a new experience with Haptic-go-round. We took notes while they elaborated details such as building steps, procedures, game plays, scenes, props, etc. Finally, we collected feedback about how to improve the current system such as the software interface, prop cartridge, control system, and dimension. It took about an hour for a participant.

Result and Discussion

8 participants who have worked with VR stated that they could integrate Haptic-go-round with their previous projects to provide haptic feedback with minor adaptations such as

layout and controls (e.g., from controllers to hand tracking). With regard to developing a new experience, P1, P7, P9 and P11 described the procedure of making their adventure games that required manipulation of a variety of interactive objects. P1, P11 and P12 suggested that special effects such as heat, sound and odor modules could be used to provide other sensory experiences. P3, P6, P8 and P9 came up with different types of battle games that involved enemy attacks such as whipping, slashing and punching from different directions. We also collected some rough ideas from the participants such as fitting rooms and platform games where the surface of Haptic-go-round served as an infinite scroll page. We continued working on 2 of the designs with the participants and together built the experiences as shown in Figure 11.

Figure 11. The finished experiences in our study2. (a) A battle game where the user can open up a menu to select weapons anytime. (b) A hammer throw game using the triangle as the grip and controlling the platform to simulate different weight.

With regard to improving the current system, both P1 and P3 suggested that we should provide some example props and corresponding scripts to speed up prototyping. P12 and P7 requested to have more than 8 slots and to make the spacing adjustable. P3 and P12 asked for providing safety mechanism for spectators. Finally, 9 participants are willing to use Haptic-go-round for their future applications.

The result of this study shows that Haptic-go-round allows VR experience designers to deploy encounter-type haptics in existing and new applications without mechanical expertise. However, both the software interface and the prop cartridge could be further optimized.

LIMITATIONS AND FUTURE WORK

As we have shown in the technical evaluation section, Haptic-go-round has an averaged 7.25 second of rotating latency and a maximum load of 10 kg. The weight has to be evenly distributed to keep the rotation platform stable. Without concerning safety, one could raise the power of the motor and strengthen the structure with a uni-body frame to support faster and heavier uses.

In our current implementation, the micro controller limits the response time of the encoder and thus decreases the resolution. One could replace with a higher frequency micro controller for better resolution.

We currently used haptic retargeting only to compensate encoder error and optional pitch offset. However, there could be some interesting interactions between the platform reaction time and haptic retargeting. For example, the user could be slowed down by larger angle of redirection to buy more time for the platform to get in place. These interactions could be further investigated in the future.

Though our work is mainly focused on the platform, there are 3 considerations that experience designers should be taking extra care of while making appropriate props for our system. Firstly, props often extrude from the cartridge and compress the user's space. This eventually attributes to the longest extruded prop because the platform rotates. Enough space and a safety margin should thus be left for the user. Secondly, as discussed in the study 1, props should be tracked properly to avoid misalignment. Lastly, connecting custom-made active components (e.g., triggers) that communicates with applications still requires additional interfacing by developers. However, using passive props can already generate rich experiences [8]. We also see the opportunity where the active components are made from VR controllers to reduce interfacing effort.

We made our current system cylinder as it allows us to quickly adjust the number of slots while maintaining each center of the cartridge the same distance to the user. It is also possible to use other form factors such as cone, pyramid, or sphere as long as they are able to mount props.

While Haptic-go-round provides a surrounding environment that enables a user to interact with haptic components around them, it supports only 1 degree of freedom– the yaw rotation. Haptic-go-round does not provide pitch movement (higher/lower) nor radiation movement (closer/further). Therefore, the effective region for prop cartridges is limited given the fixed radius. This could be a constraint for experiences. The developers have to take care of the trade-off between prop size and number of slots.

In our future work, we will look into adding extra degrees of freedom without influencing the prop deployment. We plan to add linear actuators for radiation movement and stack more than one ring frame to create a multi-layered Haptic-go-round system. We will also integrate with an omni-treadmill to allow walking-in place VR.

CONCLUSION

We have presented Haptic-go-round, a surrounding platform that allows experience designers to agilely add haptic components and provide haptic feedbacks from any direction in VR. We implemented a working platform along with a control system, a prop cartridges system, and a software interface. We have demonstrated 1 complete development process and 3 example applications to show the functionalities of Haptic-go-round. We conducted experiments to evaluate the performance of the whole system.

With Haptic-go-round, we have tackled the challenge of making a prototyping platform for encounter-type haptics. We see that Haptic-go-round together with an omni-treadmill is a feasible solution in furture VR arcades.

ACKNOWLEDGEMENT

This work was supported by Ministry of Science and Technology in Taiwan (MOST 108-2636-E-002-013).We thank the department of Mechanical Engineering at National Taiwan University especially Yi-Teng Huang and Lin Hung-Jen in the Mechanical Workshop for facilitating our prototype construction. We also thank all participants who have been contributing their creative ideas in designing the Haptic-go-round experiences.

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