Integrating Everyday Proxy Objects in Multi-Sensory Virtual Reality Storytelling

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ABSTRACT

We describe design research on the use of multiple physical proxy objects to create an engaging and compelling virtual reality experience. Physical proxies, such as a camera prop that integrates a help system into the storyline, enhance tactile immersion and may result in improved presence. We use plausible storytelling elements tied to passive haptics and reuse a single tracking device to track multiple physical proxies. This is a re-submission of an accepted paper from last year.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Haptic devices.*

KEYWORDS

Virtual Reality, VR, proxy, passive haptics, storytelling

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1 INTRODUCTION

Virtual Reality (VR) [3, 5, 6] can be defined as an interactive and immersive experience in a simulated world [14]. Immersion, presence and interactivity are features of VR that draw it away from other representational technologies [11]. However, understanding 3D spaces and performing actions in free space are often difficult for people [7]. Traditional interaction styles and techniques do not always result in realistic and compelling user experiences [2]. Physical proxy objects are one way to address these challenge, as they provide shape, weight and texture stimuli in VR in a low-cost and powerful way.

In this work, which was developed as an entry for the 3DUI Contest at the IEEE Virtual Reality Conference, we designed a 3D User Interface (UI) for a VR escape room experience (Figure 1) that employs physical proxies to provide passive haptics for several virtual objects [4].

Figure 1: A participant interacting with the blowtorch, which consists of a plastic bottle, swim noodle, and embedded pressure sensor

Our story introduced the user as an agent from the "Time Corrections Department," and tasked them with preventing an Electro-Magnetic Pulse (EMP) bomb from detonating and destroying a space elevator on Earth. The user had to find pieces of a "cryptex" that were strewn about the environment. A key plot device in the scenario was that the user could utilize a time machine to travel between pre- and post-detonation space elevator rooms. This approach afforded the reuse of the same physical space for different virtual rooms while maintaining coherence and spatial immersion. Once the user found three cryptex parts (out of a possible four) through solving small puzzles, such as a Tic Tac Toe game and a blowtorch activity, the pieces combined and provided the user with a memory cube containing the password to disarm the EMP. In all, we expected users to finish the experience within seven minutes.

Tracking each physical prop is a critical challenge for interactive proxy objects. When multiple props are used, having one tracker for each prop can be expensive and impractical. In addition, aligning the physical proxies with their corresponding virtual objects is challenging. In our design, many of the physical proxy objects are only interacted with for a short time. This means that we can re-use the same tracker for multiple objects. Our tracker is introduced to the user as a *temporal stabilizer* which is integrated into the narrative (Figure 2).

Figure 2: Different everyday proxies and 3D printed passive haptic devices.

Our design is based on a coherent narrative that draws from real-world interactions, science fiction, and existing 3D UI techniques. This narrative incorporates novel components such as a *hint camera*, a *temporal stabilizer*, and a *time machine* into the experience. These components help establish a coherent and compelling story, make transitions among the tasks fluid, and create an immersive experience that effectively uses both limited physical space and technological resources.

Providing hints for the user without ruining their feeling of presence can be challenging. We present the user with a physical prop that matches a virtual *Hint Camera* in the story. The hint camera is used during the experience to provide the users with additional hints to solve puzzles. This not only prevents interrupting the user's presence, but may actually improve it.

2 PROXY OBJECT DESIGN

Designing haptic interfaces for VR experiences has been considered challenging for a long time. Prior research has found that mismatches in shape, weight and texture of the physical and virtual objects could negatively impact the perceived realism of VR experiences [12, 15, 16]. Active force feedback interfaces utilize a single device (e.g., a handheld controller attached to a grounded mechanical arm that can display forces) to provide haptic feedback to users. They have the drawback that the user does not interact directly with the virtual object, but instead touches it or holds it with a tool.

In contrast, the passive haptic approach uses physical props that are similar in shape, weight and texture to virtual objects. Previous work has proven the viability of passive haptics to enhance presence in VR experiences [8, 9]. The physical props can be easily made and assembled with everyday materials and 3D printing technology, which reduces the cost of repeated production [9]. In this section, we discuss how we utilized passive haptics to embed multiple everyday proxies in our VR experience while maintaining a coherent narrative.

2.1 Reusing Physical Proxies

Unlike active haptic interfaces in which a single device is sufficient for haptic simulation, passive haptics need a physical proxy for every object the user will touch or interact with. Since passive haptics allow us to build real-world proxies based on virtual objects, why not design different virtual objects that are similar in shape so that we can re-use the same physical proxy for them? For example, in our experience, we re-use the same physical proxy for two interactive objects (cryptex and tic-tac-toe pieces) in two puzzles. We also re-used a puzzle piece dispenser after the user went through our virtual time machine. Since the virtual worlds in the different time periods occupy the same physical space but look completely different, we found that participants rarely noticed this. They interacted with the same physical proxies differently based on the context.

2.2 Augmenting Physical Proxies

Everyday physical proxies can be freely augmented with other components to enhance the affordances of interactions. For example, materials with different textures can be used to customize the tactile feedback. The freedom of customizing the physical proxy also makes it possible to embed low-cost electronic components into the proxies. In our design, we augment everyday proxies (plastic bottle and swim noodle) with an Arduino nano, a pressure sensor, and a HC-06 Bluetooth module to enable squeezing interactions. Users are able to adjust the fire volume of the blowtorch by adjusting the force of squeezing the swim noodle (Figure 3). We received a lot of positive feedback about this design.

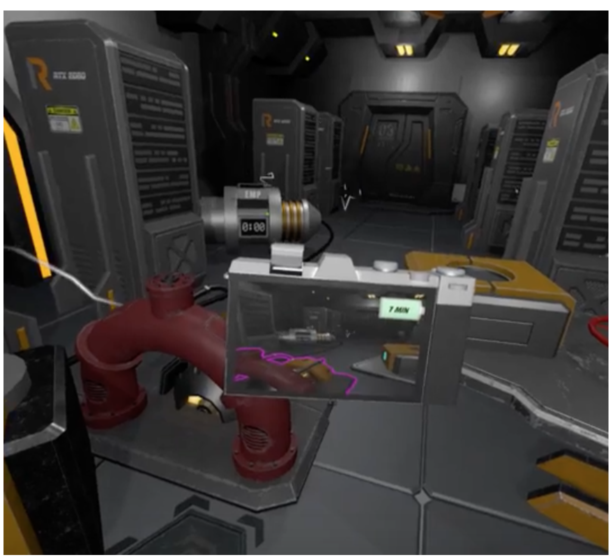

Figure 3: First-person view of the virtual escape room experience

3 INTEGRATION OF PHYSICAL PROXIES

We designed multiple physical objects that can afford various interactions. The physical props enrich users' multi-sensory feedback and should improve their sense of presence. However, the number of objects we needed for different interactions posed challenges in integration, since we aimed to seamlessly bridge the physical and virtual worlds. In this section, we document the problem encountered, the design process, and the outcome.

3.1 Reusing Physical Space

A virtual space that could support our designed narrative ended up being larger than the available physical workspace (2m by 3m). We decided to reuse the physical space by changing the story to contain multiple timelines. We created a time machine that mimics an elevator. The player is expected to walk into the time machine and press buttons to navigate through time. The time machine closes its door after the player walks in. We change the scene outside while the user is blocked in the time machine. When the door opens again, the user is brought to a different timeline with a new environment.

3.2 Reusing Tracking Devices

In our scene, we have multiple physical proxies that afford different interactions, such as wheels for rotation and pillars for placement and stacking. To transform physical movements into the virtual world, we decided to use HTC VIVE trackers. These trackers can be easily integrated into SteamVR and provide low-latency, reliable tracking. Unfortunately, the physical proxies that we designed outnumber the available VIVE trackers. Thus, we must seek ways to reuse the trackers.

There are some requirements regarding the use of the trackers. First, we should minimize the interference with its tracking performance. Some grip gestures could block the trackers' line of sight and thereby lead to poor tracking performance. We decided to avoid full grip of the tracker itself, and only do so when the user switches the tracker to a different physical proxy.

Second, we want to precisely and firmly attach the trackers to the physical proxies and also make them easily detachable when needed. For example, when the player attaches a tracker to the blowtorch, they always need to attach it at the same position with the same orientation so that they can immediately pick up the blowtorch and use it. The tracker should also be placed firmly so that there is no drift in position or orientation between the tracker and the proxy object. At first, we chose to use Velcro tape to attach the trackers to the proxy objects. While this solution is firm enough, it cannot guarantee precise alignment, and detaching the tracker is difficult. Our final solution uses magnets to attach the tracker to the proxy (Figure 4).

We first attach a 3D printed object to the tracker using Velcro. In the story, we call this object the *temporal stabilizer*, and explain to users that they should not attempt to touch or move any objects in the scene without first "stabilizing" them to avoid temporal anomalies. The object has slots that can hold two small magnets. We also place magnets on the proxy objects so that when the tracker gets near to them, the magnets attract one another. By experimenting with different numbers of magnets, we can control the tightness. By placing the magnets at pre-defined positions, we can ensure an automatic alignment as the magnets will move towards each other. Grabbing the proxy object with one hand and the stabilizer with the other makes it easy to detach the tracker when the user is done

Figure 4: Using magnets, the user can easily attach the tracker (temporal stabilizer) to different proxies, in the right position and orientation, and detach it.

interacting with the objects. Thus, the same VIVE tracker can be used to interact with most of the proxy objects in the experience.

3.3 Scene Setup

It is critical for us to align the physical proxies with their counterparts in the virtual environment. Because the players are immersed in the virtual environment and cannot see the physical world, they can only expect to interact with the virtual content at its location in virtual space. Any mismatches would break presence and jeopardize the entire experience. Thus, we need to perform pre-alignment of the physical setup.

After SteamVR defines the virtual space, the virtual world coordinates are expected to stay constant. We use tables and chairs to hold the physical proxies and change their locations to match their counterparts in VR if large-scale alignment is needed. When the tables and chairs are placed in roughly the correct positions, we perform precise adjustment in VR to match the virtual content to the physical world. After alignment, we mark down the ideal positions of the physical objects along with the tables and chairs and reset their positions after each run.

4 LESSONS LEARNED

This work helps identify some of the noteworthy factors in integrating everyday proxy objects in an immersive VR experience.

When designing with passive haptics, we need a physical proxy for every interactable object in the scene. This can be impossible or at the very least inefficient to design. Our design supports the possibility of reusing the same physical props to represent virtual objects with similar shape and texture without causing discrepancies in the user experience. As Kohli suggests, the mapping of passive haptics does not need to be one-to-one [10]. Redirected touching and haptic retargeting [1] leverage visual dominance to conceal discrepancies between our senses and between the real and virtual objects, allowing a single passive haptic device to provide adequate tactile feedback for multiple virtual objects.

Storytelling is a crucial component of a compelling experience. A good story enables many illusions that overcome the limitations of the physical proxies without the users knowledge. Having physical haptics is one way to provide a realistic and compelling user experience. However, managing these props introduces new complications and cumbersome tasks to the user experience. An intuitive and easy to understand story that supports the user's visual and tactile experience, reduces the annoyance and distraction caused by such complications. Including easy-to-understand notions such as an elevator and a temporal stabilizer in our storyline enabled us to utilize techniques such as change blindness redirection [13] and reuse the same physical space, physical proxies and tracking devices.

To design a realistic and easy-to-learn experience, it is important to considering affordances and to ensure that both the visual and the tactile interaction of the proxies are aligned. In our design, using a swim-noodle for the blowtorch and a wheel for the valve and their virtual representation, affords the everyday use of these proxies. This helps the user to intuitively know how to use each proxy without the need for training.

It is also critical to keep the application and the context of each interaction in mind when designing them. To avoid interference with the tracking device' signals, we ensured that the designed interaction does not involve direct touching of the device.

5 CONCLUSION

This work presents a 3D User Interface that employs multiple physical proxies in order to provide a compelling virtual experience. We developed design solutions within a coherent narrative framework that enabled reuse of the same physical space for two virtual rooms and reuse of the same tracking device for handling multiple proxies. Furthermore, integration of these proxies into the scenario allows smooth transitions between different tasks, keeps the user engaged, and provides hints to the user through an integral story element. Overall, the design incorporates physical proxies into the UI to offer an immersive high-fidelity experience while overcoming various VR limitations.

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