Building Reconfigurable Passive Haptic Interfaces On Demand Using Off-the-shelf Construction Bricks

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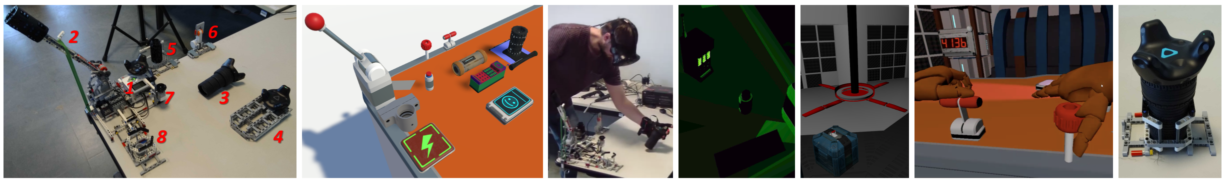

(a) (b) (c) (d) (e) (f) (g)

Figure 1: System overview: a) physical props, b) virtual objects, c) interaction, d) dark room, e–f) task examples, g) joined props.

Abstract

Although passive haptic interfaces have been shown to be capable to enhance the user's sense of presence in Mixed Reality experiences, their use is still constrained by the need to rely on exact replicas of virtual objects or on custom-made devices mimicking the original ones. Unfortunately, the former are not flexible enough in terms of reconfigurability, whereas the latter may be difficult to reproduce. To tackle these issues, this paper explores the possibility to build passive haptic interfaces using off-the-shelf toy construction bricks. Bricks can be assembled to provide the intended feedback in more than one task. Moreover, they may be reassembled in another application to mimic completely new objects and support totally different tasks.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Hardware—Communication hardware, interfaces and storage—Tactile and hand-based interfaces—Haptic devices

1 Introduction

The ability to touch and "feel" objects in a virtual environment is a feature that can help to increase the user's sense of presence in Mixed Reality experiences. Devices that aim to stimulate the human sense of touch are known as *haptic interfaces* (or *haptics*), and can be classified as *active* or *passive* depending on the underlying technology. Active haptics leverage computer-controlled actuators to exert forces on the user [9], whereas passive haptics are designed to provide him or her with a feedback through their shape, weight or other inner physical attributes or behaviors (e.g., using "energetically passive actuators which may only remove, store, or redirect kinetic energy within the system" [8]).

Most of the approaches experimented so far rely on the use of either common objects or custom-made props (often with complex hardware) selected or designed to mimic the virtual objects. These approaches are characterized by a poor flexibility and usability, which mostly limit their applicability to professional scenarios.

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To cope with the above issues, this paper proposes a new class of haptic devices that can be built "on demand" using off-the-shelf construction bricks (namely, the LEGO Mindstorms EV3 elements). The possibility to let the users assemble their own interfaces has been already explored in the field of 3D character animation [5]. In this paper, the above approach is applied to the construction of haptic devices which can be exploited in many ways within the same application and can be reassembled several times to create new interfaces tailored to varying application's requirements. For demonstration purposes, the devised methodology has been exploited to build several passive haptics to carry out a number of tasks in a Virtual Reality scenario representing an imaginary escape room.

2 Related Work

As said, haptic devices can be classified as either active or passive.

The Phantom [6] is one of the first examples of the first category. Like many active haptics, it is a grounded machine that exerts a controlled force vector on the user's fingertip. Ungrounded solutions exist too, usually in the form of wearable devices like the hand exoskeleton presented in [4]. The main advantage of active haptics lies in their versatility, since they can be easily reused in different scenarios. However, because of electro-mechanical complexity, they are often cumbersome to use [1], and it is hard to make them implement a function different than the one they have been designed for.

Passive haptics, in turn, are generally characterized by a low complexity, since no active computer-controlled actuator is normally involved. A simple but representative example of wearable passive haptics is provided by Elastic-Arm [1], a device that uses a rubber band to link the user's shoulder and wrist in order to produce a passive force feedback when he or she extends the arm. Another interesting concept is represented by the Virtual Mitten [2], an hand-held device containing springs that let the user grasp virtual objects by tightening and relaxing the hand. In [7], a squeeze feedback is provided using a foam ball. In some cases, actuators are avoided at all, and passive haptics are "simply" a physical – possibly approximated – proxy of the corresponding virtual object. In these cases, works in the literature focused on studying the appropriate level of fidelity required to provide the user with a credible feedback. The major drawback of this approach is the lack of generality of props, which translate in the need to rely on separate physical objects for each virtual object. An interesting solution to this problem was recently proposed in [3], where it was shown how two physical devices – namely, a foldable prop and a suspended ball – could be reused multiple times in the same virtual environment to simulate different objects with the user being unaware of that.

The approach presented in this paper builds upon the above concepts and integrates them in a methodology letting users assemble off-the-shelf components to build passive haptic interfaces that can be reconfigured multiple times, thus addressing both flexibility and ease of use constraints that characterize existing works.

3 System Overview

Fig. 1 provides an overview of the virtual scenario used in this paper, which is set in a futuristic nuclear power plant during an emergency. Initially, lights are off, and a phone is ringing in the dark. During the call, someone briefly explains the situation and gives some hints to deal with it. The procedure to solve the emergency consists of three stages. In the first stage, which takes place in the auxiliary power room, the user is asked to restore the facility power by acting on a lever which has to be identified in the dark with the help of the weak light coming from the keypad of the phone and by feeling the objects' shape with the hand. Afterwards, the user needs to find the device (a tablet) which activates the teleportation to the second stage. This stage is set in the control room, and the user's goal is to secure it by first enabling and then controlling a three-axis robotic arm to move boxes containing dangerous material to a safety area. To activate the robot, a battery needs to be placed in a socket and oriented properly. In the third stage, the user is teleported to the reactor room, where he has to explore the environment looking for some hidden clues which became visible when lighted by a handheld UV beamer. Clues suggest the passcode to enter in order to start the procedure for reinserting the control rods into the reactor, stabilizing the nuclear reaction and solving the emergency. The scenario was created with the Unity game engine.

As shown in Fig. 1a, bricks, servomotors and sensors in the LEGO Mindstorms EV3 Core and Expansion sets were used to build several props, each acting as a physical proxy for one or more of the virtual objects the user has to interact with in order to solve the proposed challenges (Fig. 1b). For servomotors, only the encoders were used to gather rotation data. Sensors and servomotors were connected to a LEGO Intelligent brick (Fig. 1a.1), which sends information about the state of a button, the rotation of a knob, etc. to Unity over WiFi. Like in [3], during the experience the user is unconsciously forced to reuse the same prop to carry out more than one task.

The user wears a HTC Vive Virtual Reality headset (Fig. 1c), which provides him or her with visual and audio feedback. In order to boost the sense of presence and the naturalness of interaction, a virtual representation of the user's hands was integrated in the scenario by reconstructing them in real-time. At first, hand tracking was implemented using the Leap Motion sensor. However, with this technology it was hard to deal with occlusions. Thus, the Manus VR gloves were used to retrieve fingers' articulation data. Leap Motion sensor was nonetheless considered to gather the actual size of the user's hands, which was exploited to appropriately scale the geometry of the virtual hands. The position/orientation of user's hands and passive haptics were tracked in absolute terms by attaching HTC Vive trackers to the user's wrists and to physical assemblies.

The devised props need to be exploited in the tasks listed below.

i) Identify the attributes of objects: by resembling their physical counterparts, assembled props let the user feel differences among the objects he or she interacts with in terms, e.g., of weight, shape, surface, etc. For instance, in the first stage, the user needs to find the ringing phone represented by the cylinder assembly in Fig. 1a.3 based on its haptic feedback and on the flashing keypad (Fig. 1d). Similarly, he or she has to recognize the shape of the lever in Fig. 1a.2 by moving his or her arm in the dark and touching it in order to reactivate the lights. The user also feels the shape of the tablet device in Fig. 1a.4 as well as its smooth surface when requested to place his or her hand on it for triggering teleportation.

ii) Pulling / Pushing: the lever in Fig. 1a.2 is used in the first stage to reactivate the lights, and is reused later to control the height of the robotic arm's gripper (Fig. 1e); the elastic mounted on the prop exerts a force that tries to bring back the lever to the initial position.

iii) Rotation: the physical knob in Fig. 1a.5 is used twice, first to move the robotic arm's gripper left and right during the second stage, then to change the passcode digits in the third stage (Fig. 1f). The smaller lever (with no return feedback) in Fig. 1a.6 is used to move gripper forward and backward.

iv) Pressing: the pushable prop in Fig. 1a.7 is used as a button and, depending on the challenge being addressed, can be exploited by the user to either commute the opened/closed status of the gripper or to confirm the passcode digits being inserted.

v) Insertion / Plug in: the prop used in the first stage as a phone is reused in the second stage to mimic the battery that has to be plugged in a socket (Fig. 1a.8) and rotated to power the robotic arm.

vi) Join: when plugged in the socket, the battery and the socket becomes a new, single object – the UV beamer – which can be exploited by the user to find hidden clues in the third stage (Fig. 1g).

A video with tasks and props is available at `https://youtu.be/tbruIRw9TJ4`. Instructions for building the props in Fig. 1a can be accessed at `http://vr.polito.it/papers/ieeevr2019/instructions/`. Instructions for building, with the same bricks, other props to be exploited in different tasks are also presented.

4 Conclusions and Future Work

This paper proposed the creation of reconfigurable passive haptics based on toy construction bricks, and presented their use in the execution of a number of tasks in a Virtual Reality environment. Future work will aim at the evaluation of usability (both w.r.t. assembly and use of the physical props) through user studies involving other scenarios and tasks. Moreover, mechanisms for the automatic generation of assembly instructions will be explored. The creation of further props supporting, e.g., pressure/squeeze or dynamic changes in textures and materials will be studied too. Finally, the opportunity to apply this technology also to the construction of active haptics and to Augmented Reality scenarios will be investigated.

Acknowledgments

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References

[1] M. Achibet, A. Girard, A. Talvas, M. Marchal, and A. Lécuyer. Elastic-Arm: Human-scale passive haptic feedback for augmenting interaction and perc. in virtual environments. In *Proc. IEEE VR*, pp. 63–68, 2015.

[2] M. Achibet, M. Marchal, F. Argelaguet, and A. Lécuyer. The Virtual Mitten: A novel interaction paradigm for visuo-haptic manipulation of objects using grip force. In *Proc. IEEE 3DUI*, pp. 59–66, 2014.

[3] L.-P. Cheng, L. Chang, S. Marwecki, and P. Baudisch. iTurk: Turning passive haptics into active haptics by making users reconfigure props in Virtual Reality. In *Proc. ACM CHI*, pp. 89:1–89:10, 2018.

[4] R. Hinchet, V. Vechev, H. Shea, and O. Hilliges. DextrES: Wearable haptic feedback for grasping in VR via a thin form-factor electrostatic brake. In *Proc. ACM UIST*, pp. 901–912, 2018.

[5] F. Lamberti, G. Paravati, V. Gatteschi, A. Cannavò, and P. Montuschi. Virtual character anim. based on affordable motion capture and reconfigurable tangible interfaces. *IEEE TVCG*, 24(5):1742–1755, 2018.

[6] T. H. Massie and J. K. Salisbury. The Phantom haptic interface: A device for probing virtual objects. In *Proc. ASME Haptic Int. for Virtual Env. and Teleop. Systems Symp.*, vol. 55, pp. 295–300, 1994.

[7] A. Pihuit, P. G. Kry, and M.-P. Cani. Hands on virtual clay. In *Proc. Int. Conf. on Shape Modeling and Applications*, pp. 267–268, 2008.

[8] D. K. Swanson. *Implementation of arbitrary path constraints using dissipative passive haptic displays*. PhD thesis, 2003.

[9] A. Zenner and A. Krüger. Shifty: A weight-shifting dynamic passive haptic proxy to enhance object perception in Virtual Reality. *IEEE TVCG*, 23(4):1285–1294, 2017.