A Robotic Haptic Feedback Device for Immersive Virtual Reality Applications

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Abstract. The use of virtual reality technology has become popular in modern theme parks across the world. Attractions using virtual reality technologies offer highly immersive experiences as if people are really staying in fictional worlds that the theme parks like to create. Haptic feedback is an important piece in virtual reality, where it can increase the immersion and enjoyment, but most virtual reality attractions in theme parks do not offer enough haptic feedback. In this paper, we present HapticDaijya, which is a waist-worn robot capable of giving various haptic and tactile feedback on the torso, neck, face, arms and hands. We present the design and implementation of HapticDaijya. Then, we show a user study and analyze the results for investigating its feasibility. Also, we present preliminary evaluation results that gauged the user's accuracy in distinguishing the locations of taps applied on the chest, as well as general usability and user acceptance.

Keywords: Wearable Robot; Haptic feedback; Tactile feedback;

1 Introduction

Theme parks are popular destinations for enjoying various types of attractions, rides, and events in a single location. Disneyland is one of the most famous theme parks in the world, where it has different fictional characters that visitors can interact with. Each attraction in the park is an immersive experience based on a Disney story. Because these stories are very popular, when people visit Disneyland, they feel that these fictional characters exist in the real world, that they can meet these characters and that they can enjoy being with them during their visit. In particular, incorporating fictionality through virtuality is an essential approach to enhance user experiences in theme parks [8].

Recently, the progress of virtual reality (VR) technologies offer highly immersive experiences so that the technologies will significantly change user experience in theme parks by incorporating their fictional stories through virtuality. Attractions using virtual reality technologies offer highly immersive experiences as if people are in fictional worlds that the theme parks like to create. Actually, some theme parks already adopted such technologies and successfully offer impressive immersive experiences: for example, in Japan, VR Zone Shinjuku's Ghost in the Shell: Arise Stealth Hounds[1], and Dragon Ball VR Master the Kamehameha[2], and globally, Disneyland's Star Wars: Secrets Of The Empire[3], and Universal Studio's The Repository[4]. Also, Triotech sells some VR attractions like Virtual Rabbids: The Big Maze[5]. Creative Works has developed Hologate which is a VR arcade game.[6] In these VR attractions, a head-mounted display (HMD) is a key technology to offer visual immersion, but the current VR attractions do not offer enough haptic feedback to users, where haptic feedback is essential for enabling truly immersive user experiences within VR. As most virtual reality attractions within theme parks lack haptic feedback, the existence of haptic feedback is essential in increasing the enjoyment and immersion within such attractions.

In this paper, we present HapticDaijya, which is a waist-mounted six degrees of freedom (DoFs) serpentine robot that is capable of providing various haptic experiences. HapticDaijya is able to enhance immersion through haptic feedback that can be delivered to different parts of the body. Our approach attempts to fulfil two design targets. First, HapticDaijya can be used in a variety of haptic and tactile feedback methods, such as producing normal or shear forces, as well as gestural output [1, 7], such as poking or stretching the skin. Second, HapticDaijya is capable of haptic and tactile feedback in multiple locations on the body. We present our prototype system, our preliminary evaluation and the future direction.

The structure of the paper is as follows. In Section 2, we introduce haptic feedback in VR and related work. Section 3 present an overview of HapticDaijya. Then, Section 4 shows results of the preliminary user study, and Section 5 describes its current potential pitfalls in this study. Section 6 concludes the paper.

2 Haptic Feedback in Virtual Reality and a Robotics Haptic Feedback Device

2.1 Motivation and Scenario

Haptic feedback has long been investigated as a method to increase the immersion or enhance the interaction within VR. Many modern VR HMDs, like HTC Vive[7] and Oculus Rift[8], allow players to move around physically in a tracked space while being engaged in VR. Accordingly, numerous consumer products and research literature investigated wearable haptic feedback methods for areas like the arms, hands and torso. Yet,

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[1] https://vrzone-pic.com/en/activity/koukaku.html
[2] https://vrzone-pic.com/en/activity/dragon.html
[3] https://disneyworld.disney.go.com/attractions/disney-springs/star-wars-secrets-empire/
[4] https://www.facebook.com/pages/VR-the-Repository-Universal-Orlando/1264916250217177
[5] http://trio-tech.com/products/vr-attraction/
[6] https://thewoweffect.com/products/hologate/
[7] https://www.vive.com/
[8] https://www.oculus.com/rift/

other body areas, like the neck, face, head or others, have largely been unexplored for their validity for haptic or tactile feedback, especially within the context of VR.

Figure 1 shows how a flexible robotic haptic device offers a more immersive user experiences to users. In the future, when a user is being punched on the chest and chin in the VR world, a haptic force with similar magnitude and location is applied to his chest and chin through the robotics haptic feedback device. The approach offers various opportunities to enhance the current VR attractions in theme parks.

Zero Latency is an emerging VR attraction that is globally available in various locations[9]. It is a free-roam multiplayer game. Each player wears an HTC Vive VR HMD, headphones, a backpack containing a high-performance computer. Here, we would like to explain how a robotics haptic feedback device can be used to enhance the game experience through a scenario. We explain how our approach may significantly improve a player's overall VR user experience.

Fig.1 Robotics Haptic Feedback Device in a VR Environment

Each player holds a controller which is a simulated weapon. Eight players are divided to two teams to fight and they will also meet zombies in the game which exist in the VR game world. While the game is played, a player is attacked by an enemy who is near him. The bullet shoots the player's chest, and at the same time, the device applies a similar haptic stimulus by hitting player's chest with matching location and power magnitude. The player runs away and hides in the back of a box. At this time, there is another enemy trying to approach the player. Since the player holds a radar property which is able to detect live person's activity in five meters, the device gently pats the player's shoulder twice, to notify him about the approaching player. The player turns back quickly and finds the enemy. He shoots the enemy and avoids being attacked. Suddenly the device holds his hand, the player turns around and finds that there is a zombie that holds his hand in the VR game world. He casts off the device and gives the zombie a shot.

2.2 Related Work

Previous researches have investigated a variety of feedback methods that can enhance VR experiences. Several researches explored vibrotactile feedback at various locations on the body, especially the chest [4, 5]. Other researches attempted to simulate impacts

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[9] http://tokyo-joypolis.com/attraction/1st/zerolatency/

and pressure using solenoids a vest [1]. Yet, such feedback remains confined to predetermined points and is limited to a single type.

While there exists a large body of works around vests for vibrotactile feedback around the torso [4, 10], such works remain limited in terms of the diversity of haptic or tactile feedback as well as their capability to deliver feedback to other locations on the body. Also, surveyed literature and products were mainly confined to delivering feedback to fixed stimulation points (as in [5]) and were mostly capable of vibrotactile feedback.

Alternate reality experiences [3] refer to a human experience felt by refining the meaning of real space by incorporating virtuality [9]. An alternate reality experience is typically achieved by modifying our eyesight or replacing our five senses to others, and offers a promising possibility for implicitly influencing our attitudes and behaviors in everyday life. For example, human eyesight can be altered using head-mounted displays (HMDs), which modify real-world views captured by video cameras attached to the HMDs with virtual reality technologies. Similarly, visual color images can be transformed to sounds for color-blind people, or visual stimuli can be converted into vibrations to reduce the visual cognitive load.

3 HapticDaijya

3.1 Basic Design

Fig.2 Overview of HapticDaijya

In this section, we present the basic design issues in HapticDaijya, where Daijya (大蛇) means a big snake in Japanese. Our device looks like a snake that is capable of providing various of haptic feedback through its snake-like behavior. The main design objective of our approach is rich haptic feedback in a wearable form. To further extend previous works by diversifying haptic feedback, we designed a waist mounted serpentine-shaped robot with an end effector as shown in Figure 2. We have chosen the serpentine morphology as it's high DoFs allow the attached end effector to deliver a variety of haptic feedback. Moreover, such flexibility allows the robot to also reach the user's face, neck, shoulders and arms.

Using the robot end effector as described in Section 3.2, HapticDaijya can apply various types of normal and shear forces with varied durations and magnitudes. Furthermore, by varying and combining forces, HapticDaijya can provide a variety of feedback, such as pushing, pulling, hitting, scratching and pinching. Gestural feedback [7] can also be created by applying directional and tangential forces on the user's body.

3.2 Device Structure and Functionality

Fig.3 Various Feedback Effects by HapticDaijya

HapticDaijya consists of the following components.

Robot: Our implementation uses six hobby servomotors (EZ Robot [2], Stall torque = 19 kg/cm) connected serially in a serpentine formation (Figure 2). The total length of the robot is 51 cm and weighs 742g. The robot is mounted on a base, which holds an EZ-B robot microcontroller [2].

Vest: The base of the robot is strapped to a vest, weighing 300g. The vest makes the robot comfortable and easy to wear or take off.

Control: The EZ-B microcontroller is remotely controlled by a PC through Wifi. The control software was developed under the EZ-Builder framework and integrated with the Unity3D game engine using a client-server architecture.

With exchangeable end effectors, HapticDaijya can deliver a variety of haptic feedback in a variety of locations as shown in Figure 3. Such capability is not limited to expanding the range of haptic feedback types, but to also match distinct user preferences or ergonomic requirements. For instance, taller users may use bigger or longer end effectors so the robot arm may reach all their torso areas, and sensitive individuals may use softer or padded end effectors.

The haptic and tactile feedback can be used for purposes beyond VR games. For example, drawing the user's attention to hazards and emergencies, like earthquakes, or to deliver smartphone notifications. In combination with exchangeable end effectors, additional applications such as feeding users during VR gaming are possible.

4 Preliminary User Study

4.1 Research Method

To perform a preliminary test and evaluate our robot, we designed an experiment that gauges users' accuracy in determining the location of taps that are applied to various locations of the torso. We accordingly followed the experiment with questionnaires and interviews to evaluate general usability aspects.

We hired ten college students (Age m=22.80, SD=2.94, 6 Females). Each participant was first introduced to the robot and took a profiling questionnaire. Next, we carried out the *calibration* process, followed by the *tutorial*, which comprised a single dry run for each of the 16 calibrated points. Such process familiarized participants with the feedback on all 16 locations. As shown in the left part in Figure 4, the torso is segregated into 16 cells. Cells 1 through 4 are aligned horizontally to four points on the collar bone and shoulders of each participant. The remaining 12 cells are aligned with 5-8 cm vertical spacing. The robot was calibrated to tap the center of each cell from an approximate distance of 10 cm using the maximum servo speed and full torque. The test took approximately 20 minutes per participant.

The *trials phase* started by first blindfolding the participants to simulate a VR experience. Each trial included a single tap on one of the 16 points, then each participant verbally indicated the point at which they believed they received the feedback.

We repeated the trials three times for each of the 16 points, thereby subjecting each participant to 48 taps. The trials were randomized to avoid possible learning effects. In total, we carried out 480 successful trials.

4.2 Results

Figure 4-Left illustrates the haptic feedback point-matrix on the user's torso. Each cell represents a region where the robot applied haptic feedback. Overall, participants achieved the highest accuracy levels on the first row and the sides, after which their accuracy gradually drops as shown Figure 4-Right (SD values in brackets)

Our questionnaire used a 5-point Likert scale (1 is Disagree/Bad, 5 is Agree/Good). Participants rated "*I can easily distinguish the feedback among different points"* with 3.40 (SD=1.07) and "*I can distinguish feedback among contiguous points*" with 2.70 (SD=0.95). Most participants also indicated that identifying feedback on the edges of the torso is easier than the center, asserting that feedback on cells 1 through 4 is easier to identify as it is near the collarbones and shoulders.

Participants rated the comfort of our device with 3.80 (SD=0.79) and the weight with 2.3 (SD=0.95), thus we conclude that the wearability of the device was generally acceptable. Lastly, they rated their overall satisfaction with 3.80 (SD=0.92).

Overall, we concluded that other factors, such as the intensity of the taps as well as our chosen cell locations and dimensions, may have contributed to these results. Nevertheless, we believe such results are intriguing to validate further.

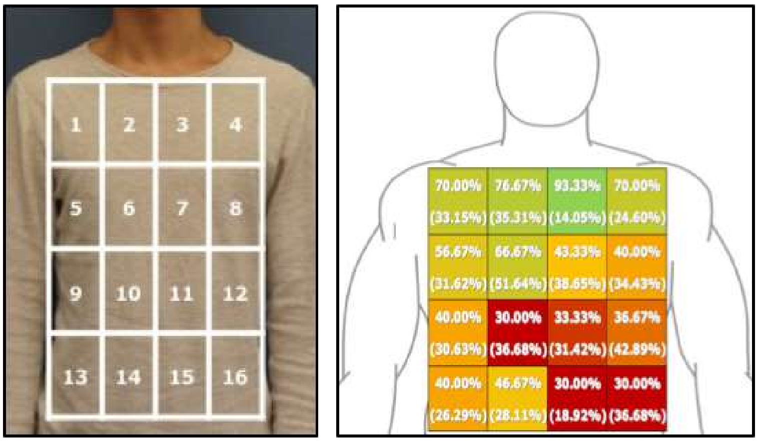

Fig.4 User Study: Procedure and Results

5 Some Pitfalls Found in the Current Experiences

From the experiences with the current prototype, we have extracted the following potential pitfalls. In particular, analyzing our prototype within the context of the scenario described in Section 2 allowed us to extract a number of usability and implementation shortcomings. For example. although our prototype allows for manually changeable end-effectors to deliver various feedback types, future iterations must embed an automated end-effector changing mechanism to deliver a variety of haptic feedbacks without delay. Such limitations may restrict the possibilities of games significantly, but it may not be a good idea just simply to increase a number of robotic components.

In the following, we also present some pitfalls found during the design, implementation, and evaluation.

Visuo-haptic synchronization: Despite the variety of possible haptic feedback, the serpentine morphology imposes several limitations. Since the robot has to move to different points to apply feedback, there is an unavoidable delay in orienting and moving the robot. This is especially prevalent if the visual feedback in VR is much faster or very frequent, such that it outpaces the robot's ability to synchronously deliver haptic feedback in accordance with visual stimuli.

Simultaneous Haptic Feedback: Another shortcoming of the serpentine morphology is its incapability to deliver multiple haptic feedback impulses in parallel. For example, as described in the scenario shown in Section 2, a player may be attacked at two different positions on his/her body by two different enemies. The current hardware cannot provide the corresponding haptic feedbacks simultaneously at two different positions.

Movement Obstruction: The workspace of HapticDaijya may easily collide with hand movements of the user, especially since most modern VR platforms utilize hand controllers or gestures for interaction. This problem may be solved by context awareness to avoid collisions, or a smaller design that stays closer to the user's chest.

Calibration: An easy and precise calibration method ensures replicable and high quality user experiences. A quick calibration method is important for instantly fulfilling a user's ergonomic differences. Moreover, thick clothes, like jackets, could absorb feedback, thus, delivered feedback should be adapted to variance in users' clothing. Lastly, delicate Areas like the neck or the shoulders present calibration and safety challenges for delivering haptic feedback.

6 Conclusion

In this paper, we present HapticDaijya, a wearable haptic and tactile feedback robot. We presented our initial design and implementation, followed by an analysis of advantages and limitations. Our initial evaluations are overall encouraging to pursue further development, and the survey results are intriguing for further investigation.

In the future, we would like to realize a complete a multi-user attraction using HapticDaijya. In the future theme park, such advanced attractions require various haptic feedback and more immersion. We believe our future work contribute with various useful insights that will make future theme parks more enjoyable.

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