HapticSerpent: A Wearable Haptic Feedback Robot for VR

Mohammed Al-Sada
Qatar University, Qatar
Waseda University, Tokyo, Japan
alsada@dcl.cs.waseda.ac.jp

Keren Jiang
Waseda University, Tokyo, Japan
jiangkeren@dcl.cs.waseda.ac.jp

Shubhhankar Ranade
Waseda University, Tokyo, Japan
Shubhi@dcl.cs.waseda.ac.jp

Xinlei Piao
Waseda University, Tokyo, Japan
Xinlei1020@dcl.cs.waseda.ac.jp

Thomas Höglund
University of Vaasa
thomas.hoglund@uva.fi

Tatsuo Nakajima
Waseda University, Tokyo, Japan
tatsuo@dcl.cs.waseda.ac.jp

CHI'18 Extended Abstracts, April 21–26, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3188518

Abstract
Haptic feedback is an important part of virtual reality (VR), where it can increase the immersion and enjoyment. Within VR, research literature and products are mainly limited to vibrotactile feedback for the torso. We believe that additional types of haptic feedback around other areas of the body could potentially yield interesting VR experiences. Thus, we present HapticSerpent, which is a waist-worn robot capable of various haptic feedback on the torso, neck, face, arms and hands. We present our implementation specifications, followed by an initial evaluation to measure the distinguishability of taps applied to the torso. Also, we surveyed the acceptability of receiving feedback in different locations on the body. Participants noted an overall higher accuracy on the upper and sides of the torso and they generally disfavored haptic feedback in sensitive areas due to potential harm. Lastly, we discuss various research opportunities and challenges and present our future direction.

Author Keywords
Wearable; Robot; Haptic feedback; Tactile feedback;

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): H.5.2 User Interfaces

Figure 1: (Upper) A user is being punched in the chest in VR. (Lower) A haptic force with similar magnitude and location is applied to his chest through the HapticSerpent arm.

Introduction

Haptic feedback has long been investigated as a method to increase the immersion or enhance the interaction within virtual reality (VR). Many modern VR platforms, like HTC Vive and Oculus Rift, 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, 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.

While there exists a large body of works around vests for vibrotactile feedback around the torso [3,7,8,9], 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.

In this paper, we present HapticSerpent, which is a waist-mounted six degrees of freedom (DoFs) serpentine robot arm that is capable of providing various haptic experiences (Figure 1). Our approach attempts to fulfil two design targets. First, contrary to previous literature and existing commercial products, HapticSerpent can provide a variety of haptic feedback types, such as producing normal or shear forces, as well as gestural output [1,4], such as poking or stretching the skin. Second, HapticSerpent is capable of haptic feedback in multiple locations on the body (Figure 1). We present our prototype specifications, followed by our preliminary evaluation and the future direction. Next, we discuss the advantages of our design direction within the context of haptic feedback, highlighting various challenges and opportunities for future work. Lastly, we present our future direction.

In this paper, our contributions are the following:

1) The design and implementation of a wearable haptic/tactile feedback robot that is capable of a variety of feedback methods in multiple locations on the body.

2) Preliminary evaluation results that *A)* gauge the user’s accuracy in distinguishing the locations of taps applied on the chest, as well as general usability and user acceptance. *B)* General acceptability of receiving feedback from HapticSerpent on different areas of the body.

Related Work

Previous works have investigated a variety of feedback methods that can enhance VR experiences. Several works explored vibrotactile feedback at various locations on the body, especially the chest [5,7]. Other works attempted to simulate impacts and pressure using solenoids a vest [4]. Yet, such feedback remains confined to predetermined points and is limited to a single type.

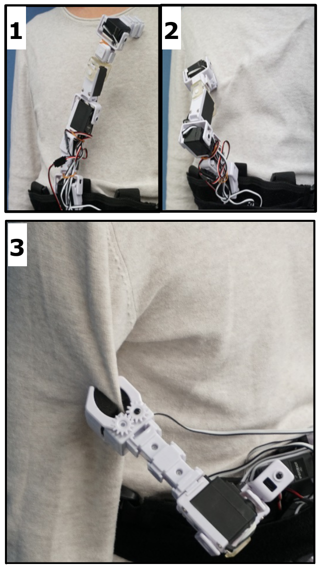

Figure 3: (1-2) HapticSerpent scratching the user's chest diagonally. (3) Pinching and pulling the user's clothes. Such types of feedback can be applied with varied magnitudes, directions and speeds.

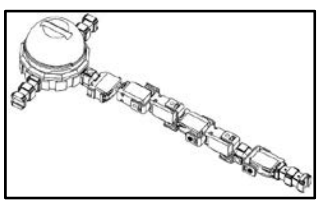

Figure 4: Our robot is comprised of sequentially connected servomotors in the above arrangement.

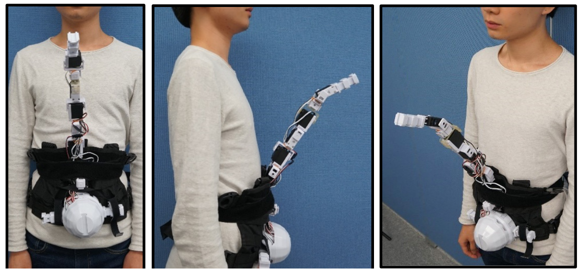

Figure 2: Front, side and oblique views of HapticSerpent

Likewise, various commercial products like Hardlight VR [3] and Eyeronman [9] are vests that embed vibrotactile motors for feedback similar to previously mentioned literature. Lastly, ARAIG [10] utilizes inflatable bladders to simulate impact or pressure applied to the torso.

Thus, we conclude that surveyed literatures and products were mainly confined to delivering feedback to fixed stimulation points (as in [5]) and were mostly capable of vibrotactile feedback.

HapticSerpent

Design: The main design objective of our approach is rich haptic and tactile feedback in a wearable form. To extend previous works by diversifying haptic feedback, we designed a waist mounted serpentine-shaped robot with an end effector (Figure 2).

We have chosen the serpentine morphology as its high DoFs allow the attached end effector to deliver a variety of haptic feedback. Moreover, such flexibility also allows the robot to reach the user's face, neck, shoulders and arms.

Haptic Feedback: Using the robot end effector, HapticSerpent can apply various types of normal and shear forces with varied durations and magnitudes. Furthermore, by varying and combining forces, HapticSerpent can provide a variety of feedback, such as pushing, pulling, hitting, scratching and pinching (Figure 3.3). Gestural feedback [1] can also be created by applying directional and tangential forces on the user's body (3.1 and 3.2).

Prototype

Robot: Our implementation uses six hobby servomotors (EZ Robot [2], Stall torque = 19 kg/cm) connected serially in a serpentine formation (Figure 4). 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 300 g. 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.

Initial User Study

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

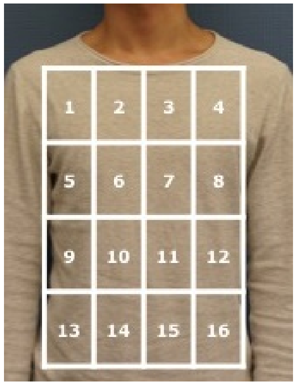

Figure 5. The torso is divided into 16 cells. Cells 1 through 4 are aligned horizontally to four points on the collarbone and shoulders of each participant.

The remaining 12 cells are aligned with 5 to 8 cm vertical spacing, depending on the person's chest size. The robot was calibrated to tap the center of each cell from an approximate distance of 5 cm using the maximum servo speed and full torque. The test took approximately 20 minutes per participant.

Participants and Procedure: We hired 10 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 (As described in Figure 5), followed by the *tutorial*, which comprised a single dry run for each of the 16 calibrated points. This process familiarized the participants with the feedback in all 16 locations.

The *trials phase* started by first blindfolding the participant to simulate a VR experience. Each trial included a single tap on one of the 16 points, after which the participant verbally indicated the point at which he/she believed the feedback was received.

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 taps.

Results

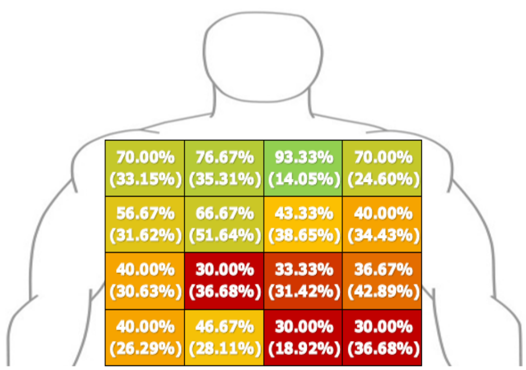

Figure 6: This figure illustrates the average accuracy of distinguishing taps in each location (average standard deviation in brackets).

Feedback Accuracy: As shown in Figure 6, participants achieved the highest average accuracy levels on the first row and the sides, after which their accuracy gradually drops.

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). Several participants also indicated that identifying feedback on the edges of the torso is easier than the center (Figure 6), asserting that feedback on cells 1 through 4 is easier to identify as it is near the collarbones and shoulders.

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.

Hardware: Participants rated the comfort of our device with **3.80** (SD=0.79) and the weight with **3.7** (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).

Survey of Preferred Feedback Areas

Objective and Participants: Our secondary evaluation gauged the users' acceptance of receiving various types of feedback through HapticSerpent. Thus, we surveyed 28 college students who had previous experience of VR (23 males).

Procedure: We created a survey based on a 5-point Likert scale (1 is Very Unacceptable, 5 is Very Acceptable). Each question gauged a specific area on

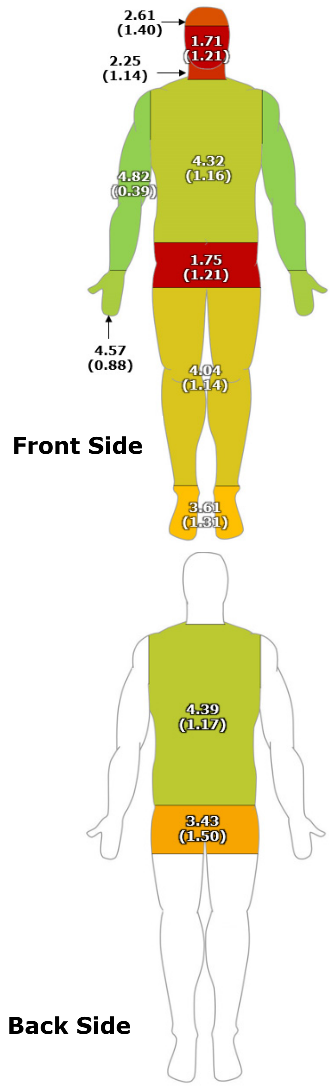

Figure 7

the body as shown in Figure 7. Prior to answering, the participants were briefed about HapticSerpent and its feedback capabilities.

Results: As shown in Figure 7, Participants voted highest acceptability for the torso, arm, hand, legs and back areas, and they gave medium scores for the feet and butt areas. People were generally skeptical about receiving feedback on delicate areas like the head or waist, yet some thought it could be acceptable. 39% of participants scored 3 or above for feedback on the *head*, 20% for the *face*, 29% for the *neck*, and 18% for the *waist* areas. Participants also elaborated that feedback like tickling on the cheeks or gentle face taps would be tolerable.

We believe the acceptability of feedback in delicate areas is dependent on the feedback type and how trustworthy the hardware is, which demands reliable and fail-proof future implementations.

Challenges and Opportunities

+ *Varied Feedback Locations*: Unlike other vest worn devices, HapticSerpent can deliver feedback to areas beyond the torso. For example, the neck area, upper arms, and forearms (As shown in Figure 8).

+ *Extended Feedback:* With exchangeable end effectors, HapticSerpent can deliver a variety of haptic feedback (Figure 8). This capability not only expands the range of haptic feedback types, but also allows it to accommodate distinct user preferences or ergonomic differences. For instance, taller users may use bigger or longer end effectors so that the robot arm may reach the whole torso.

+ *Multifunctional:* With exchangeable end effectors, our robot could be utilized for a variety of experiences beyond haptic feedback. For instance, feeding the user in VR, or delivering wind-effects to the user's face (Figure 9), are some of the potential VR experiences.

+ *Varied Applications:* Feedback can be used for purposes beyond VR experiences. For example, drawing the user's attention to hazards and emergencies, like earthquakes, or for smartphone notifications. Haptic feedback can be utilized for breaking VR immersion.

- *Visuo haptic/tactile synchronization*: Despite its versatility, the serpentine morphology imposes several limitations. Since the robot arm must move to different points to apply feedback, there is an unavoidable delay in orienting and moving the arm. This is especially prevalent if the visual feedback in VR is much faster or very frequent, such that it outpaces the capability of the robot arm synchronously to deliver haptic feedback in accordance with visual stimuli.

- *Simultaneous Haptic/Tactile Feedback:* Another shortcoming of the serpentine morphology is its incapability to deliver multiple haptic feedback impulses in parallel. Thus, further morphologies should be investigated, such as a multi-arm robot.

- *Unintended Feedback:* As most users utilize VR joysticks, the robot arm could collide with the users' hands, resulting in unintended haptic feedback. Moreover, quick user movements, such as leaning forward, could result in overshooting intended feedback force magnitude or location. Such issues require further optimization in the wearability and mechanical design.

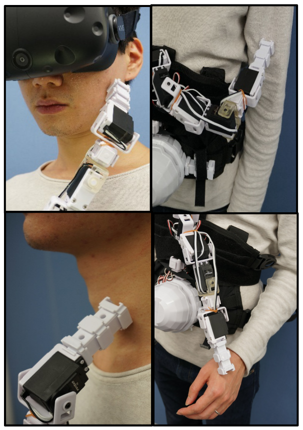

Figure 8: Different types of feedback could be applied to various body locations

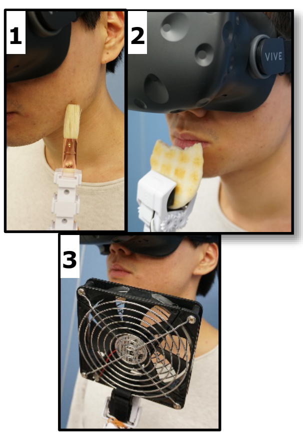

Figure 9: 1) a brush tickling the cheeks. 2) Feeding the user using a gripper. 3) A fan blowing air on user's face. Future iterations may integrate automatically changing end effectors.

- *Calibration:* An easy and precise calibration method ensures a replicable and high-quality user experience. A quick calibration method is important for instantly adapting to differences between users. Moreover, thick clothes, like jackets, could absorb delivered feedback, thus, feedback should be adapted to variance in users' clothing. Lastly, delicate areas, like the neck present calibration and safety challenges for haptic feedback.

Conclusion and Future Work

In this paper, we presented HapticSerpent, a wearable haptic feedback robot. We presented our initial design direction, followed by an analysis of advantages and limitations. The results of our initial evaluations overall encourage us to pursue further development and the survey results are intriguing to explore further.

HapticSerpent should be further mechanically improved in terms of actuation and design. Specifically, better mechanical design would both improve feedback control and ergonomics. Other morphologies should also be explored, both for enabling simultaneous feedback and for overcoming delay caused by serpentine morphology.

References

1. Anne Roudaut, Andreas Rau, Christoph Sterz, Max Plauth, Pedro Lopes, and Patrick Baudisch. 2013. Gesture output: eyes-free output using a force feedback touch surface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 2547-2556. DOI: https://doi.org/10.1145/2470654.2481352
2. EZ-Robot Inc. Retrieved January 07, 2018, from https://www.ez-robot.com/
3. Hardlight VR. Retrieved January 07, 2018, from http://www.hardlightvr.com/
4. Anne-Marie Corley Posted 26 Mar 2010 | 16:51 GMT. (2010, March 26). Tactile Gaming Vest Punches and Slices. Retrieved January 12, 2018, from spectrum.ieee.org/automaton/robotics/robotics-software/tactile-gaming-vest-punches-and-slices
5. Yukari Konishi, Nobuhisa Hanamitsu, Kouta Minamizawa, Benjamin Outram, Tetsuya Mizuguchi, and Ayahiko Sato. 2016. Synesthesia suit: the full body immersive experience. In *ACM SIGGRAPH 2016 VR Village* (SIGGRAPH '16). ACM, New York, NY, USA, , Article 20 , 1 pages. DOI: https://doi.org/10.1145/2929490.2932629
6. Ahmed Al Maimani and Anne Roudaut. 2017. Frozen Suit: Designing a Changeable Stiffness Suit and its Application to Haptic Games. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17). ACM, New York, NY, USA, 2440-2448. DOI: https://doi.org/10.1145/3025453.3025655
7. Lynette A Jones, Mealani Nakamura and Brett Lockyer. 2004."Development of a Tactile Vest", In Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2004. HAPTICS '04. Proceedings. 12th International Symposium.
8. Steven W. Wu, Richard E. Fan, Christopher R. Wottowa, Eileen G.Fowler, James W.Bisley, Warren S.Grundfest, Martin O. Culjat. 2010. "Torso-based tactile feedback system for patients with balance disorders", In Haptics Symposium, 2010 IEEE.
9. Tactile Navigation Tools- Eyeronman, http://tactilenavigationtools.com
10. ARAIG - Multi-Sensory VR Feedback Suit. https://araig.com/