Enhancing Understanding of Human Haptic Perception on the Body

BINGJIAN HUANG, Department of Computer Science, University of Toronto, Canada
DANIEL WIGDOR, Department of Computer Science, University of Toronto, Canada

Haptic feedback are widely applied in daily scenarios and commerical devices. More recently, researchers are seeking novel solutions to integrate haptic devices to Virtual Reality experience. Despite the large amount of research on inventing new haptic hardware, human perception of haptic feedback in virtual environment is only primitively investigated and not well understood yet. Therefore, this paper summarizes the previous work in the "human localization perception" area, remaining problems in the area, how authors plan to resolve the problems.

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

Additional Key Words and Phrases: Haptic Feedback, Human Perception, Psychophysics, Vibrotactile Actuators

ACM Reference Format:
Bingjian Huang and Daniel Wigdor. 2018. Enhancing Understanding of Human Haptic Perception on the Body. In *Woodstock '18: ACM Symposium on Neural Gaze Detection, June 03–05, 2018, Woodstock, NY*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/1122445.1122456

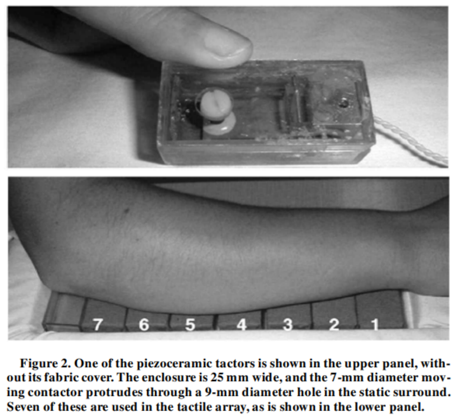
1 INTRODUCTION

The touch modality serves as an important part of human sensory system. Research on haptic devices has long been an exciting research topics in Human-Computer Interaction. In the early work, haptic devices were designed for people with visual impairments in order to read texts and perceive shapes [3]. In more recent research, the usage of haptic devices expands to applications of more variety, including vision-occupied scenarios (e.g., driving [11]), remote operation (e.g., surgical robots [1]), and virtual environment (e.g., Virtual Reality gaming and training [17]). A large number of new haptic devices were invented in the academia, and some were even adopted by the industry to become parts of the latest commercial products [2, 24].

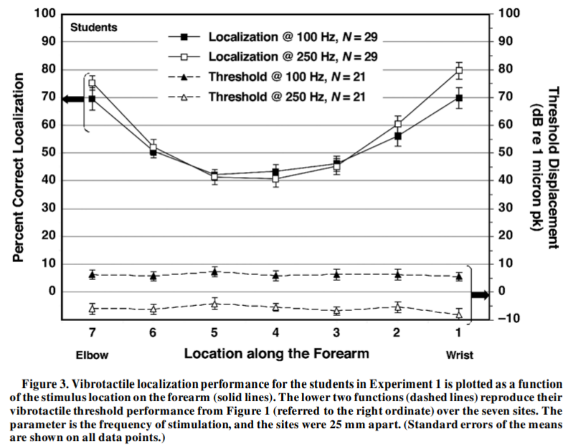
In virtual reality (VR) related haptic research, the majority focuses on providing haptic feedback to the hands, because hands are extensively used for VR interaction and operations [12, 20, 23]. When people want to feel something, they tend to use their hands to touch the object (i.e., active feedback). Therefore, haptic feedback on the hands can indeed greatly enhance immersive experience. However, as more and more VR applications support full-body interaction [10, 14, 19], people have the needs to represent themselves by avatars and this adds the requirement of passive haptic feedback, which means providing haptic feedback to the body.

In prior work, researchers have attempted to cover the surface of the body with vibrating motors [18, 21] or pneumatic actuators [7, 22]. However, these solutions are often low in resolution, providing only 20-30 feedback options for the entire body. To date, there has yet to be a fine-grained, accurate, high-resolution approach that can provide feedback

Manuscript submitted to ACM



(a) Testing scene of Chloewiak et al's study[5]



(b) Results: percentage correctness of each motor

Fig. 1

to the entire human body surface. Therefore, the goal of the our research is to provide full-body and high-resolution haptic feedback to the entire human body in a cost-effective and non-intrusive way.

As the first step towards the final goal, it is required that we need to understand how human perceive haptic stimuli on the body. More specifically, how accurately human can localize certain kinds of haptic stimuli on the body? The answer to this question will inform haptic designers the required resolution of haptic devices at certain body locations.

Prior research has attempted to measure the human perception of localization by several methods and gained different results. One classic method is called spatial discrimination. In the study design, multiple vibrotactile motors are placed at equal distances. The participant is asked to indicate which motor provides the stimulus when one of them is activated randomly. Results are reported as the percentage of correct answers for each motor. In early work such as Chloewiak et al's study [5], a linear array of seven vibrotactile motors were attached to the forearm and percentage correctness was measured. Results showed that localization is more accurate when stimuli are close to joints (elbow, wrist) compared with stimuli in the middle (Figure. 1). Chloewiak et al also performed a similar study on the torso [4]. More recently, VibrationCap [8] measured the percentage correctness of 19 positions on the head and concluded that the back regions generally have higher accuracy. To summarize, the spatial discrimination method provides great insights into human localization capability, but it also has problems. Since it measures discrete identification of individual motors, it lacks continuous details about the exact location where human perceive the stimulus. It is difficult to tell whether there is any bias towards the left or right, or what is the variance of perception.

To address this gap, a research method called localization error is applied to measure perceived locations and variances. The participant is asked to point out exactly where the stimulus is felt when one motor is activated. results are reported as the MEAN and SD of the relative error between perceived locations and physical locations. For instance, Kerdegari et al [17] and Kaul et al [16] used this method to measure vibrotactile perception on the head. They attached a headband to multiple head regions. They reported localization error for each motor and head region and found that there were centralizing biases towards the mid-line of the head (Figure.2). VibroMap [9] used the method to measure localization variance in six body locations and two directions. In their results, however, they slightly modified the

(a) Testing Scene of Kerdegari et al's study[17]

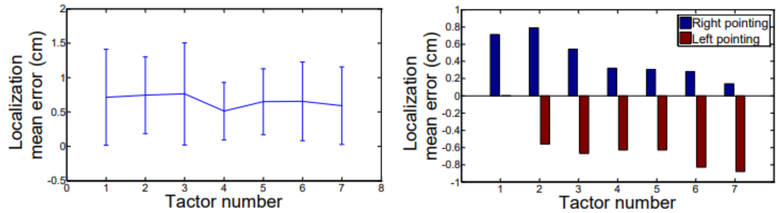


Fig. 4. Left: Localization mean error, Right: Localization mean error for left and right sides.

(b) Results: localization mean errors

Fig. 2

definition of localization error by eliminating directionality of error. They defined Localization error as "*the absolute distance between where the participant feels the vibration and the location of vibrotactile actuator*". They reported the 95% Confidence Interval as the localization error.

Besides the localization error method, another method called relative spatial acuity is also frequently used in recent work. The stimuli consisted of the sequential activation of two vibrotactile motors. The participant was asked to indicate whether the second stimulus was to the left or the right of the first stimulus (Two-alternative forced choice, 2AFC). In some cases, users were given the third choice that both stimuli are from the same motor, forming the 3AFC design. Hoffman et al [13] used 4x4 array of three types of vibrotactile motors to measure the spatial acuity on the back. Results showed that types of motors and testing directions have strong influence on the percentage correctness results. Likewise, Jóhannesson et al [15] used a tactile vest and a vibro-sponge with different spacing to measure the spatial acuity of the torso. Their results showed that when motor spacing is 40mm on the vest, percentage correctness is around 75%. When motor spacing decreases from 30mm to 13mm on the sponge, percentage correctness also decreases from 90% to 60%. Moreover, Oliveira et al [6] measures the spatial acuity on head regions. Instead of just reporting percentage correctness, they calculated the percentages for each distance condition and fit them to Psychometric functions to get the Just Noticeable Difference (JND) values. They found that frontal area has generally higher acuity (lower JND) than occipital and temporal areas.

Despite the substantial amount of work on the localization measurement topic, designers still find that it is difficult to take the results from these papers as reference. One potential reason behind this problem is the generalization capability of conclusions from different vibrotactile motors. In most of the prior work, authors used one specific kind of motor to measure human perception and report localization results. If readers plan to use the same motor, it is reasonable to take the previous results as background knowledge. However, if readers plan to use a motor that is different in vibration direction, frequency, size, or amplitude, it is difficult to know whether the previous results are still valid or not. Therefore, it is very important to perform the same localization research method on different types of motors.

In my current research project, I am working on building a localization testing haptic device with several different kinds of vibrotactile motors, including ERM, LRA-Z, and LRA-X, etc. I plan to adopt the relative spatial acuity method to measure localization performance on several body regions, and see if it is possible to find connections between vibration properties and localization performance. This work is still in progress, I believe more details can be shared at the time when the workshop is held in April.

ACKNOWLEDGMENTS

place for acknowledgement.

REFERENCES

[1] Farshid Amirabdollahian, Salvatore Livatino, Behrad Vahedi, Radhika Gudipati, Patrick Sheen, Shan Gawrie-Mohan, and Nikhil Vasdev. 2018. Prevalence of haptic feedback in robot-mediated surgery: a systematic review of literature. *Journal of robotic surgery* 12, 1 (2018), 11–25.

[2] bHaptics. 2022. *bHaptics TactSuit X40.* bHaptics. https://www.bhaptics.com/tactsuit/tactsuit-x40

[3] Hyouk Ryeol Choi, SW Lee, Kwang Mok Jung, Ja Choon Koo, SI Lee, HG Choi, Jae Wook Jeon, and Jae-Do Nam. 2004. Tactile display as a braille display for the visually disabled. In *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)(IEEE Cat. No. 04CH37566)*, Vol. 2. IEEE, 1985–1990.

[4] Roger W Cholewiak, J Christopher Brill, and Anja Schwab. 2004. Vibrotactile localization on the abdomen: Effects of place and space. *Perception & psychophysics* 66, 6 (2004), 970–987.

[5] Roger W Cholewiak and Amy A Collins. 2003. Vibrotactile localization on the arm: Effects of place, space, and age. *Perception & psychophysics* 65, 7 (2003), 1058–1077.

[6] Victor Adriel de Jesus Oliveira, Luciana Nedel, Anderson Maciel, and Luca Brayda. 2016. Spatial discrimination of vibrotactile stimuli around the head. In *2016 IEEE Haptics Symposium (HAPTICS)*. IEEE, 1–6.

[7] Alexandra Delazio, Ken Nakagaki, Roberta L. Klatzky, Scott E. Hudson, Jill Fain Lehman, and Alanson P. Sample. 2018. Force Jacket: Pneumatically-Actuated Jacket for Embodied Haptic Experiences. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*. ACM Press, Montreal QC, Canada, 1–12. https://doi.org/10.1145/3173574.3173894

[8] Vincent Diener, Michael Beigl, Matthias Budde, and Erik Pescara. 2017. VibrationCap: studying vibrotactile localization on the human head with an unobtrusive wearable tactile display. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*. 82–89.

[9] Hesham Elsayed, Martin Weigel, Florian Müller, Martin Schmitz, Karola Marky, Sebastian Günther, Jan Riemann, and Max Mühlhäuser. 2020. Vibromap: Understanding the spacing of vibrotactile actuators across the body. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (2020), 1–16.

[10] Guo Freeman and Divine Maloney. 2021. Body, Avatar, and Me: The Presentation and Perception of Self in Social Virtual Reality. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW3, Article 239 (Jan. 2021), 27 pages. https://doi.org/10.1145/3432938

[11] Yoren Gaffary and Anatole Lécuyer. 2018. The use of haptic and tactile information in the car to improve driving safety: A review of current technologies. *Frontiers in ICT* 5 (2018), 5.

[12] Seongkook Heo, Jaeyeon Lee, and Daniel Wigdor. 2019. PseudoBend: Producing Haptic Illusions of Stretching, Bending, and Twisting Using Grain Vibrations. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. ACM, New Orleans LA USA, 803–813. https://doi.org/10.1145/3332165.3347941

[13] Rebekka Hoffmann, Vigdís Vala Valgeirsdóttir, Ómar I Jóhannesson, Runar Unnthorsson, and Árni Kristjánsson. 2018. Measuring relative vibrotactile spatial acuity: effects of tactor type, anchor points and tactile anisotropy. *Experimental brain research* 236, 12 (2018), 3405–3416.

[14] VRChat Inc. 2022. *VRChat Offical Website*. VrChat Inc. https://hello.vrchat.com/

[15] Ómar I Jóhannesson, Rebekka Hoffmann, Vigdís Vala Valgeirsdóttir, Rúnar Unnþórsson, Alin Moldoveanu, and Árni Kristjánsson. 2017. Relative vibrotactile spatial acuity of the torso. *Experimental brain research* 235, 11 (2017), 3505–3515.

[16] Oliver Beren Kaul, Michael Rohs, Benjamin Simon, Kerem Can Demir, and Kamillo Ferry. 2020. Vibrotactile funneling illusion and localization performance on the head. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[17] Hamideh Kerdegari, Yeongmi Kim, Tom Stafford, and Tony J Prescott. 2014. Centralizing bias and the vibrotactile funneling illusion on the forehead. In *International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*. Springer, 55–62.

[18] Yukari Konishi, Nobuhisa Hanamitsu, Kouta Minamizawa, Ayahiko Sato, and Tetsuya Mizuguchi. 2016. Synesthesia suit: the full body immersive experience. In *ACM SIGGRAPH 2016 Posters*. ACM, Anaheim California, 1–1. https://doi.org/10.1145/2945078.2945149

[19] Marc Erich Latoschik, Daniel Roth, Dominik Gall, Jascha Achenbach, Thomas Waltemate, and Mario Botsch. 2017. The effect of avatar realism in immersive social virtual realities. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology*. 1–10.

[20] Yongkwun Lee and Dongseok Ryu. 2008. Wearable haptic glove using micro hydraulic system for control of construction robot system with VR environment. In *2008 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems*. IEEE, 638–643.

[21] Robert W. Lindeman. 2004. Towards Full-Body Haptic Feedback: The Design and Deployment of a Spatialized Vibrotactile Feedback System. In *Proc. of ACM Virtual Reality Software and Technology (VRST) 2004*. 10–12.

[22] Yuhu Liu, Satoshi Nishikawa, Young ah Seong, Ryuma Niiyama, and Yasuo Kuniyoshi. 2021. ThermoCaress: A Wearable Haptic Device with Illusory Moving Thermal Stimulation. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–12. https://doi.org/10.1145/3411764.3445777

[23] Thomas H Massie and JK Salisbury. 1994. The PHANToM haptic interface: A device for probing virtual objects. In *Proceedings of the ASME Dynamic Systems and Control Division*.

[24] Dexta Robotics. 2022. *Dexta Robotics - Touch the Untouchable.* Dexta Robotics. https://www.dextarobotics.com/

A APPENDIX

place for appendix.