2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Wrist-Worn Circumferential Pressure Feedback for Conveying Directional Forces in Virtual Reality

Adam Kadmani[1], Jan U. Bartels[1], Natalia Sanchez-Tamayo[1,2], Walter Gasparetto[3], and Katherine J. Kuchenbecker[1]

I. Introduction

Wrist-worn haptic devices provide hands-free, non-restrictive haptic feedback in both virtual environments and real-world applications [1]. However, a common limitation is the restricted number of actuators that can fit around the wrist, constraining the expressiveness of these devices. To overcome this spatial limitation in other contexts, researchers have explored phantom sensations – illusory tactile sensations perceived between the actual stimulation points on the skin [2]. We believe that this phenomenon can be used to render 2D directional cues using a small number of haptic actuators in a wristband, i.e., guiding a user's attention or movement direction by creating a tactile force perceived to occur at a specific location around the wrist.

Schaefer et al. demonstrated the ability of wrist-worn vibrotactile devices to induce phantom sensations for rotational wrist guidance [3]. Henell et al. demonstrated that phantom sensations can occur with pressure stimuli to the forearm [4]. While research on this topic has primarily focused on vibrotactile feedback, the potential of pressure-based cues for directional guidance around the wrist remains largely unexplored. Vibrotactile cues can be difficult to localize, particularly when multiple actuators are activated simultaneously [5]. Since pressure-based cues have demonstrated improved localization accuracy compared to vibrotactile cues [6], exploring pressure-based feedback or combined pressure/vibration feedback could enhance cue localization while avoiding the discomfort and numbing sensations often resulting from continuous vibrotactile stimulation [7].

We present a system for studying pressure-based phantom sensations in wrist-worn haptic devices. Our approach centers on a custom-fabricated bracelet with four independently controlled electrohydraulic actuators. We propose three hypotheses to study the perception of multi-directional pressure cues at the wrist, accompanied by the design of a user study to test these hypotheses.

[1]Adam Kadmani, Jan U. Bartels, Natalia Sanchez-Tamayo, and Katherine J. Kuchenbecker are with the Haptic Intelligence Department, Max Planck Institute for Intelligent Systems, Stuttgart, Germany. E-mail: {akadmani, jub, nsanchez, kjk}@is.mpg.de

[2]Natalia Sanchez-Tamayo is also with the Robotics Materials Department, Max Planck Institute for Intelligent Systems, Stuttgart, Germany.

[3]Walter Gasparetto is with the Robotics Central Scientific Facility, Max Planck Institute for Intelligent Systems, Stuttgart, Germany. E-mail: gasparetto@is.mpg.de

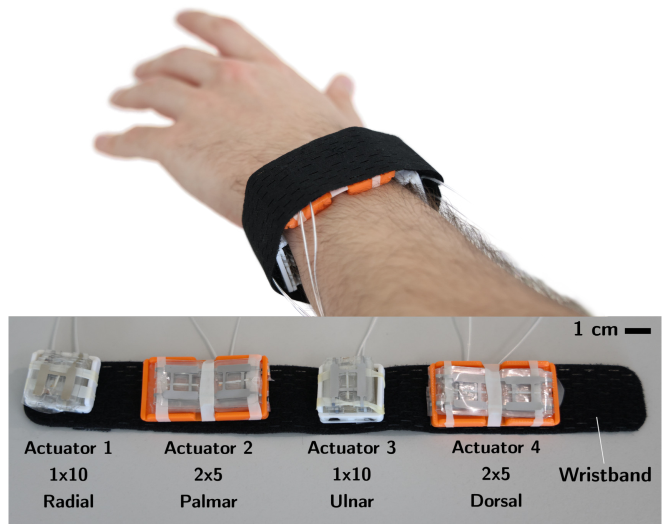

Fig. 1. Cutaneous electrohydraulic bracelet with repositionable mechanical mounts for two square 1×10 actuators and two rectangular 2×5 actuators.

II. Device

Our device (Fig. 1) consists of a bracelet with four cutaneous electrohydraulic (CUTE) actuators [8] placed against the skin at the cardinal sides of the wrist (radial, palmar, ulnar and dorsal). To accommodate the oblong cross section of the human wrist, we use two actuator variants created by distributing ten actuator pouches differently (Fig. 2). First, a square stack with ten pouches (1×10) on top of one another, which is the original CUTE design [8], is placed on both the radial and ulnar sides of the wrist. Then, we place a rectangular design of two stacks of five pouches (2×5) on the dorsal and palmar sides of the wrist. The 2×5 folding pattern was created to enable stimulation over a larger area, thereby increasing coverage of the dorsal and palmar sides. Additionally, we mount the actuators directly on the skin to utilize them in their strongest configuration (low displacement) [8].

This electrohydraulic array system offers several technical advantages that derive from CUTE devices: a flat frequency response across 0–200 Hz, silent operation, a slim 3 mm profile, and high subjective pleasantness ratings [8]. All four actuators are powered by a portable multi-channel high-voltage (HV) supply (Artimus HV).

Each actuator is housed in a 3D-printed holder made from eSUN PLA+ and Bambu Lab ABS materials. The holder design incorporates a recessed raceway for the high-voltage

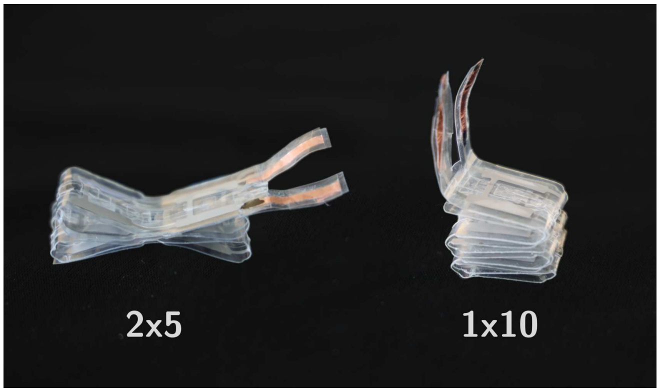

Fig. 2. 2×5 actuator fold and 1×10 actuator fold.

leads on its posterior side. The holders attach to a Velcro wristband, allowing for rapid alignment of each actuator with the wrist's cardinal points across different participants. The entire bracelet weighs 24 g.

III. Hypotheses

Based on our novel wrist-worn haptic device that can independently press on the four sides of the wearer's wrist, we formulated three hypotheses to explore the perception of directional cues. Our research focuses specifically on how pressure actuation can create distinguishable directional feedback around the wrist, a topic with significant potential but limited prior investigation. The following hypotheses guide the experimental design of our planned user study:

1) **H1** – Pressure actuation at cardinal locations around the wrist enables reliable discrimination of cardinal directional cues.
2) **H2** – Proportional pressure from two adjacent actuators creates perceptually distinct diagonal directional cues.
3) **H3** – When the actuation ratio between adjacent actuators is smoothly modulated, the user perceives a directional tactile force that continuously moves around the wrist between the two involved locations.

IV. Planned User Study

To evaluate these hypotheses, we propose an experiment on pressure-based feedback around the wrist for spatial guidance. Participants with diverse VR experience levels will be recruited to ensure the broad applicability of our findings.

A. Direction Identification Task

This task aims to evaluate the accuracy of directional perception around the wrist using static pressure feedback (**H1**, **H2**). Each participant wears the haptic bracelet and is presented with a pressure stimulus in one of sixteen directions (four cardinal, twelve diagonal). For cardinal directions, a single actuator is activated; for diagonal directions, two adjacent actuators are activated with either different or equal intensity. After each stimulus, the participant indicates the perceived direction on a rotary knob GUI. Each direction is presented five times in random order. Key metrics include the consistency of directional perception around the wrist, across trials, and across participants, as well as response time.

B. Path Guidance Task

The objective of this task is to guide the participant's hand along a predetermined planar path conveyed solely through a traveling pressure sensation around the wrist (**H2**, **H3**). The participant will first practice this task with visual and haptic feedback; during the actual trials, visual feedback is removed, requiring reliance on haptic feedback alone. To generate these cues, the hand's position is projected onto the path, and the bracelet applies pressure that combines forward guidance (along the path's tangent) and corrective feedback (toward the nearest point on the path). The participant moves their hand in response to the stimulation. Movements are tracked using a Meta Quest controller and compared to the original path for assessment. Key metrics include RMS tracking error, NASA TLX, and a subjective measure of perceptual continuity (7-point Likert scale).

V. Conclusions and Future Work

We present a haptic device with four independent cutaneous electrohydraulic actuators that can apply pressure and vibrations circumferentially around the user's wrist. Using this system in VR, we will study 2D directional cues by investigating pressure-based phantom sensations with a refined version of the presented study. Moving forward, we also plan to develop additional demonstrations to investigate how this new type of haptic feedback can be utilized in diverse scenarios.

VI. Acknowledgments

The authors thank the International Max Planck Research School for Intelligent Systems (IMPRS-IS) for supporting Jan Ulrich Bartels and Natalia Sanchez-Tamayo.

References

[1] Z. Ma, Y. Liu, D. Ye, and L. Zhao, "Vibrotactile wristband for warning and guiding in automated vehicles," in *Extended Abstracts of the ACM CHI Conference on Human Factors in Computing Systems*, pp. 1–6, May 2019.

[2] G. Park and S. Choi, "Tactile information transmission by 2D stationary phantom sensations," in *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, pp. 1–12, Apr. 2018.

[3] N. Schäfer, J. Seiler, B. Latsch, M. Kupnik, and P. Beckerle, "Vibrotactile phantom sensations in haptic wrist rotation guidance," *IEEE Transactions on Haptics*, Feb. 2025.

[4] E. Henell, J. Weda, S. Cedermalm, L. Eklöv, M. Håkansson, J. Nordström, M. Reibring, J. Stålhand, N.-K. Persson, A. Mader, J. B. van Erp, and E. W. Jager, "Pressure stimuli and spatiotemporal illusions on the forearm," *IEEE Transactions on Haptics*, vol. 17, pp. 742–752, May 2024.

[5] D. Wang, C. Peng, N. Afzal, W. Li, D. Wu, and Y. Zhang, "Localization performance of multiple vibrotactile cues on both arms," *IEEE Transactions on Haptics*, vol. 11, pp. 97–106, Aug. 2017.

[6] C. du Pasquier, L. Tessmer, I. Scholl, L. Tilton, T. Chen, S. Tibbits, and A. Okamura, "Haptiknit: Distributed stiffness knitting for wearable haptics," *Science Robotics*, vol. 9, Dec. 2024.

[7] A. A. Stanley and K. J. Kuchenbecker, "Evaluation of tactile feedback methods for wrist rotation guidance," *IEEE Transactions on Haptics*, vol. 5, pp. 240–251, June 2012.

[8] N. Sanchez-Tamayo, Z. Yoder, P. Rothemund, G. Ballardini, C. Keplinger, and K. J. Kuchenbecker, "Cutaneous electrohydraulic (CUTE) wearable devices for pleasant broad-bandwidth haptic cues," *Advanced Science*, vol. 11, Sept. 2024.