Adaptive and Immersive XR Interactions with Wearable Interfaces (Demo of KAIST HCI Tech Lab)

Sang Ho Yoon
KAIST
Daejeon, Republic of Korea
sangho@kaist.ac.kr

Youjin Sung
KAIST
Daejeon, Republic of Korea
672@kaist.ac.kr

Kun Woo Song
KAIST
Daejeon, Republic of Korea
kwsong0725@kaist.ac.kr

Kyungeun Jung
KAIST
Daejeon, Republic of Korea
kyungeun.jung@kaist.ac.kr

Kyungjin Seo
KAIST
Daejeon, Republic of Korea
kjseo@kaist.ac.kr

Jina Kim
KAIST
Daejeon, Republic of Korea
jina1190@kaist.ac.kr

Hyung Il Yi
KAIST
Daejeon, Republic of Korea
hylee0922@kaist.ac.kr

Nicha Vanichvoranun
KAIST
Daejeon, Republic of Korea
nizetime@kaist.ac.kr

Hanseok Jeong
KAIST
Daejeon, Republic of Korea
hsjeoong@kaist.ac.kr

Hojeong Lee
KAIST
Daejeon, Republic of Korea
leeho@kaist.ac.kr

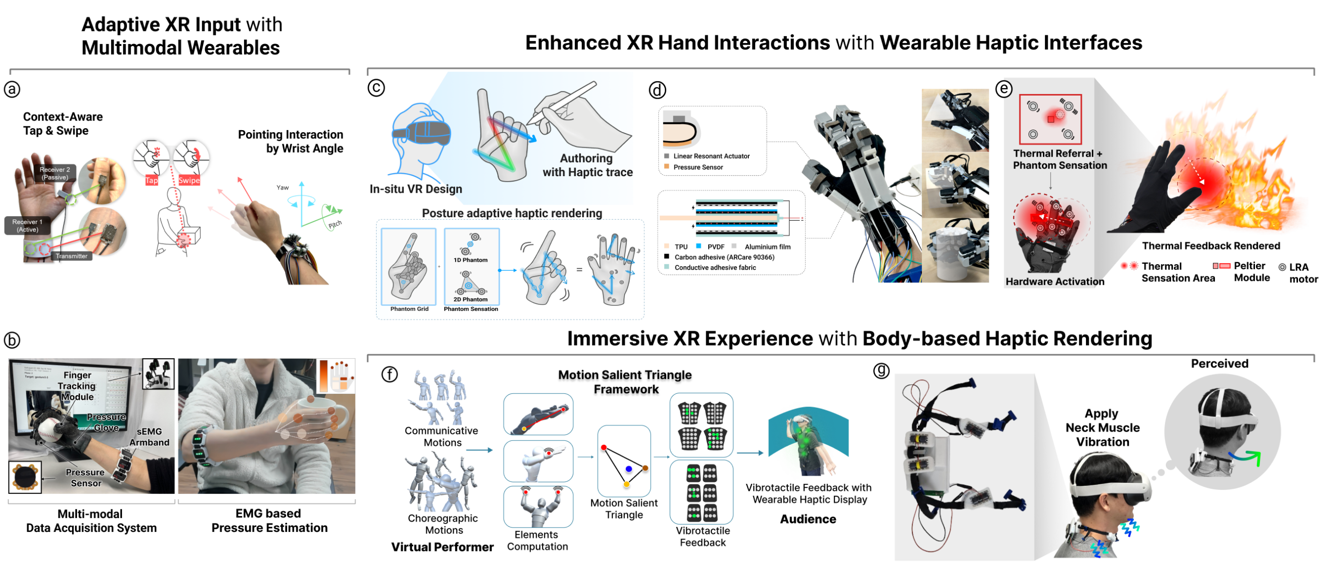

Figure 1: We present seven interactive demos that enhance the XR experience with adaptive and immersive wearable interfaces: (a) context-aware microgestures and pointing interactions, (b) robust palm pressure estimation using forearm electromyography, (c) In-situ posture adaptive haptic authoring tool, (d) multi-joint force feedback glove for enhanced virtual object shape perception, (e) dynamic thermal rendering haptic glove, (f) a pipeline for motion-to-tactile experience, and (g) neck muscle vibration system to reduce VR sickness.

ABSTRACT

In this Interactivity, we present a lab demo on adaptive and immersive wearable interfaces that enhance extended reality (XR) interactions. Advances in wearable hardware with state-of-the-art software support have great potential to promote highly adaptive sensing and immersive haptic feedback for enhanced user experiences. Our research projects focus on novel sensing techniques, innovative hardware/devices, and realistic haptic rendering to achieve these goals. Ultimately, our work aims to improve the user experience in XR by overcoming the limitations of existing input control and haptic feedback. Our lab demo features three highly enhanced experiences with wearable interfaces. First, we present novel sensing techniques that enable a more precise understanding of user intent and status, enriched with a broader context. Then, we showcase innovative haptic devices and authoring toolkits that leverage the captured user intent and status. Lastly, we demonstrate immersive haptic rendering with body-based wearables that enhance the user experience.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**; **Interaction devices**; **Interactive systems and tools**.

KEYWORDS

Interactive Technologies, Sensing Technique, Haptics, Wearables

ACM Reference Format:

Sang Ho Yoon, Youjin Sung, Kun Woo Song, Kyungeun Jung, Kyungjin Seo, Jina Kim, Hyung Il Yi, Nicha Vanichvoranun, Hanseok Jeong, and Hojeong Lee. 2024. Adaptive and Immersive XR Interactions with Wearable Interfaces (Demo of KAIST HCI Tech Lab). In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '24), May 11–16, 2024, Honolulu, HI, USA*. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3613905.3648652

1 INTRODUCTION

Wearable interfaces have been utilized for XR interactions with their advantages in ergonomic comfort, compact form factors, multimodal sensing capabilities, and personalized haptic feedback availability. These characteristics allow wearable interfaces to bring better user experiences, such as high-performance input control performance and realistic haptic sensation. Still, existing interfaces utilize wearable interfaces with traditional Window Icon Menus Pointer (WIMP) interfaces. We believe that the adoption of wearable interfaces has the potential to advance interactions in XR by supporting more personalized and realistic experiences.

With the advancement in wearable sensors, different types of sensors could be integrated or configured in a single device with a wearable form factor. This allows the wearable interface to extract more personalized data, which could be utilized to understand each user's intention more precisely. In this way, we would improve the input control's robustness and enable interactions that facilitate the user's intent, which we refer to as adaptive interaction. We explored the potential of employing adaptive interaction for sensing and haptic feedback. In terms of sensing, we utilized active and passive bio-acoustic sensing to understand the context in which users perform tap and swipe gestures [2]. On the other hand, we developed a posture adaptive haptic authoring tool that preserves the designed haptic feedback regardless of the given hand posture [3].

Wearable interfaces are a good candidate for a haptic feedback medium, as their form factors allow them to fit closely to the human body. This would provide great advantages for haptic feedback with minimal energy loss from the device to the user. Taking advantage of these benefits, our lab is working on several research projects. First, we integrate wearable force feedback gloves with vibrotactile actuators to support realistic grasping sensations [5]. We also use 3D motion data from avatar to provide meaningful motion-to-tactile sensation with upper-body wearables [1]. In addition, we are currently working on the method of using vibrotactile actuation to reduce VR sickness.

The Human-Centered Interactive Technologies Lab (HCI Tech Lab) at KAIST is a multidisciplinary research group exploring novel interactions for XR through sensing & haptic feedback technology. Our lab comprises computer scientists, engineers with various backgrounds (mechanical, electrical, material, etc.), and designers specializing in sensing techniques, haptics, and intelligent authoring systems.

In this Interactivity, we present seven demonstrations from recently published works and work-in-progress projects. Figure 1 illustrates the overview of our approaches for enhancing the XR interactions with wearable interfaces in three areas: 1) Adaptive XR input, 2) XR Hand Interactions, and 3) Immersive XR experience. We address challenges from each area by employing novel sensing techniques and haptic feedback methods to enable adaptive and immersive XR interactions.

2 ADAPTIVE XR INPUT WITH MULTIMODAL WEARABLES

Hands are one of the main control mediums for XR interactions. Understanding sophisticated hand-related information is crucial to providing a seamless and realistic user experience. However, the current XR devices in the form of Head Mount Displays (HMDs) have a limited range of hand tracking and cannot support subtle hand gestures. Aligned with this direction, we further demonstrate novel sensing techniques that enrich hand interactions in a more adaptive manner.

2.1 Context-Aware Microgestures and Pointing Interactions

Hand-tracking in XR provides users with convenient ways to interact. However, traditional HMD-based hand-tracking systems often require line of sight, which leads to inherent limitations that inhibit seamless and natural interactions. There is a growing need for adaptive gestures that can execute commands in different constraint scenarios to address these challenges. Here, we implemented

CHI EA '24, May 11–16, 2024, Honolulu, HI, USA

ACM ISBN 979-8-4007-0331-7/24/05
https://doi.org/10.1145/3613905.3648652

Vibaware [2], allowing tap and swipe gesture recognition in different task contexts. We further extend our research into support pointing interaction to complement the full-hand interactions in XR scenarios. In this demo, we will present a wrist-worn ray-casting device. The device continuously estimates the 2-DoF wrist motion angle (pitch & yaw) and recognizes ray-casting gestures by integrating the time-of-flight infrared sensor, photoplethysmography, and inertial measurement unit. We will show several real-time pointing interaction scenarios with discrete command gestures.

2.2 Robust Palm Pressure Estimation using Forearm Electromyography

To bridge the gap between the physicality of the real world and the immersive virtual environment, it is crucial to understand the physical forces that users exert and reflect them in the virtual world. However, sensor-attached gloves should be worn to measure the hand pressure. In recent work, the machine learning approach enables the estimation of the fingertip forces with electromyography (EMG). This demo will demonstrate a more advanced EMG-based sensing approach that estimates the force transmitted by the user's palm, including fingertip areas in various postures or conditions. The audience will wear EMG armbands and interact with real objects. Then, our proposed sensing technique will visualize the 3D hand posture and the pressure distribution heatmap in real time.

3 ENHANCED XR HAND INTERACTIONS WITH WEARABLE HAPTIC INTERFACES

As XR technology advances, users increasingly desire immersive experiences that mimic real-world interactions, complete with full sensory feedback. However, designing adaptive haptic experiences that cater to different objects is a challenging task to enhance user immersion. A key challenge in haptic design lies in integrating hardware considerations, rendering techniques, and user experience. Unlike other sensory information, humans feel haptic information in various physical properties, including force, heat, and vibration. This section demonstrates three adaptive haptic technologies for empowering immersive user-hand interaction.

3.1 HapticPilot: In-situ Posture Adaptive Haptic Authoring Tool

Haptic designers, often referred to as hapticians, specialize in creating multisensory experiences that incorporate various elements, such as visual and audio effects. As VR evolves to include more hand interactions and affective features in XR scenarios, users expect more haptic patterns to match these scenarios for greater immersion. However, applying haptic patterns from one scenario to another is not always effective. This is because haptic perception varies significantly based on hand postures, such as making a fist [4]. To address this, we developed a toolkit that enables the automatic generation of intended haptic sensations through simple drawing interactions in VR. This ensures that designers can convey the exact haptic experience they envision, regardless of the user's hand posture or actions in VR.

We will present **HapticPilot** [3], an in-situ haptic experience design for hand wearables in VR. We applied our posture-adaptive haptic rendering algorithm with a novel haptic design abstraction called the phantom grid. As an authoring tool, our toolkit provides a consistent haptic experience across different hand postures.

3.2 Multi-joint Kinesthetic Feedback Glove for Enhanced Virtual Object Shape Perception

Kinesthetic feedback gloves are populated in VR applications, as they create an immersive and realistic experience with a sense of touch when interacting with virtual objects. Still, existing works support only a single location for applying braking force to each finger. This hinders users' immersion since single-location force feedback makes rendering various object shape sensations hard. Thus, we are working on a lightweight multi-joint kinesthetic feedback glove crafted from an electrostatic clutch [5]. We employed a multi-layer design to increase the force feedback capability while maintaining the form factor. Also, we added LRA motors to enrich the tactile sensation.

In our demo, users will wear the prototype glove and grasp objects of various shapes. While interacting with virtual objects, our prototype will provide unique haptic feedback where users can distinguish various object shapes with the given haptic feedback.

3.3 Dynamic Thermal Rendering Haptic Glove for Immersive VR Experience

Previous methods of providing thermal feedback with wearables have often required advanced material science knowledge and complicated external hardware such as air compressors or hydraulic pumps. We will demonstrate dynamic thermal feedback rendering that integrates thermal referral and phantom sensation using Peltier and LRA motors. The thermal referral is a thermal illusion that allows the user to feel the temperature at the nearby heat source area using thermal and tactile stimuli. The phantom sensation is an illusion that operates two or more vibrotactile motors to create the sensation of a moving vibration.

In this demo, users will wear our glove prototype that renders integrated illusion of thermal referral and vibrotactile phantom sensation. Here, participants will interact with virtual thermal objects, and thermal feedback will be given in real time.

4 IMMERSIVE XR EXPERIENCE WITH BODY-BASED HAPTIC RENDERING

Haptic rendering enhances VR immersion by forming a more complete multimodal experience. However, VR applications require context-aware algorithms to provide appropriate and realistic haptic feedback. To do this, we must translate the information to render haptic feedback based on acquired VR scene information. This section showcases two context-aware haptic rendering studies that facilitate user immersion through motion-to-tactile translation and sensory mismatch deduction.

4.1 HapMotion: Rendering VR Performance Motion Flow to Upper-Body Vibrotactile Feedback

With the rise of VR musical performances, audiences can participate and actively engage in virtual concerts without physically being there. As the level of immersion increases, audiences tend to project themselves onto the virtual performers. This induces the embodiment of the audiences during VR performances. We present a **HapMotion** [1], an autonomous haptic rendering pipeline that translates the performer's entire 3D motion data into meaningful vibrotactile haptic feedback. We propose Motion Salient Triangle (MST), a novel real-time approach utilizing 3D coordinate and orientation values from skeleton data. HapMotion promotes an immersive VR performance by integrating vibrotactile aids with an autonomous haptic feedback generation pipeline. Participants will wear customized upper-body haptic suits and enjoy the VR performance embedded with motion-associated haptic feedback.

4.2 Reducing VR Sickness Caused by Circular Vection through Neck Muscle Vibration

We also explore using neck muscle vibration (NMV) to reduce VR sickness. A well-accepted theory behind the cause of VR sickness is the sensory mismatch between the virtual visual and the rest of the senses, which are grounded in reality. Here, we use tactile stimulation of the neck to lower the sensory mismatch between the visual and the proprioception. NMV stimulates the neck muscle spindles creating a perceived sensation of muscle elongation. To replicate the sensation of neck rotation, we place voice coil actuators on the left & right sternocleidomastoid (SCM) muscles (front of the neck) and left & right splenius capitis (SC) muscles (back of the neck). The actuators are then activated to match circular vection caused by visual rotations in a VR environment. We investigate the effects of NMV on VR sickness for circular vection with different camera rotation control methods. Participants will wear our prototype and experience circular vection with and without the proposed NMV system.

5 CONCLUSION

This lab demo showcases our key approaches to enabling adaptive and immersive interactions in XR with wearable interfaces. We illustrate scientific and technological challenges to bring these interactions forward with proposed wearable interfaces from the HCI Tech Lab at KAIST. We will present seven in-depth user-centered demonstrations in separate stations within our lab demo space. Attendees will experience our lab's recent works toward adaptive and immersive XR interactions in three themes: 1) adaptive XR input powered by novel sensing techniques, 2) wearable haptic interfaces for XR hand interaction, and 3) body-based immersive haptic rendering. We will bring working prototypes for each demonstration where attendees will have full access to the working prototype. We will also showcase a catered user experience application for each demonstration so that attendees can easily understand our research goal and the user benefits we have created. Furthermore, we will display posters for each demonstration and place a display to introduce our demo to the whole Interactivity attendees.

ACKNOWLEDGMENTS

We would like to acknowledge all past and current members of the lab. The projects presented in this submission are based on the broader body of our lab's research projects carried out by all our lab members. Their contributions to the lab are invaluable, and we are thankful to work with such a dedicated and talented group of individuals.

This research was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 00210001) and (No. 2022R1A4A5033689) and Ministry of Culture, Sports and Tourism(MCST) and Korea Creative Content Agency (KOCCA) in the Culture Technology(CT) Research & Development Program 2023 (No.00216939) and (No.00219020).

REFERENCES

[1] Kyungeun Jung, Sangpil Kim, Seungjae Oh, and Sang Ho Yoon. 2024. HapMotion: motion-to-tactile framework with wearable haptic devices for immersive VR performance experience. *Virtual Reality* 28, 1 (2024), 13. https://doi.org/10.1007/s10055-023-00910-z

[2] Jina Kim, Minyung Kim, Woo Suk Lee, and Sang Ho Yoon. 2023. VibAware: Context-Aware Tap and Swipe Gestures Using Bio-Acoustic Sensing. In *Proceedings of the 2023 ACM Symposium on Spatial User Interaction (SUI '23)*. Association for Computing Machinery, New York, NY, USA, Article 6, 12 pages. https://doi.org/10.1145/3607822.3614544

[3] Youjin Sung, Rachel Kim, Kun Woo Song, Yitian Shao, and Sang Ho Yoon. 2024. HapticPilot: Authoring In-Situ Hand Posture-Adaptive Vibrotactile Feedback for Virtual Reality. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 7, 4, Article 179 (jan 2024), 28 pages. https://doi.org/10.1145/3631453

[4] Youjin Sung, Yitian Shao, Rachel Kim, and Sang Ho Yoon. 2022. Exploring Vibration Intensity Map Of Hand Postures For Haptic Rendering In XR *(VRST '22)*. Association for Computing Machinery, New York, NY, USA, Article 56, 2 pages. https://doi.org/10.1145/3562939.3565672

[5] Nicha Vanichvoranun and Sang Ho Yoon. 2023. A Lightweight Wearable Multi-joint Force Feedback for High Definition Grasping in VR. In *2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 625–626. https://doi.org/10.1109/VRW58643.2023.00155