Augmented Body Parts: Bridging VR Embodiment and Wearable Robotics

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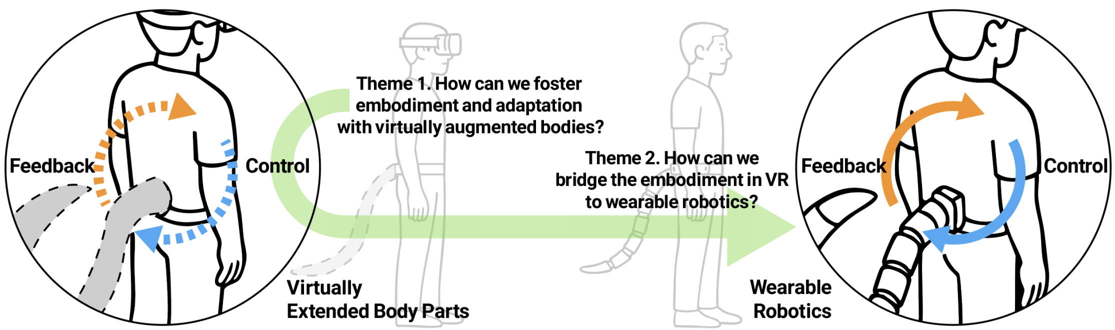

Figure 1: Overview of the workshop focus: we examine the gap between studies of virtually augmented body parts in VR and implementations with wearable robotics in physical environments, which share the goal of augmenting the human body with new parts and capabilities.

Abstract

Recent work across HCI/HRI and wearable robotics has investigated how people control and perceive extra body parts in both virtual and physical settings. Virtual embodiment in XR has shown that users can experience ownership and agency with non-anthropomorphic avatars, while wearable robotics has introduced supernumerary limbs such as third arms and robotic tails. Despite these shared goals, connections between findings remain limited because VR and hardware studies rely on different assumptions about sensory feedback, human perception, and physical constraints, making insights difficult to transfer across contexts. This workshop brings together researchers in XR, wearable robotics, haptics, and neuroscience to explore how to foster embodiment and adaptation with augmented body parts, and how to bridge virtual embodiment to effective use with wearable devices. Through a keynote, brief position shares, and two hands-on group activities, participants will examine control mappings and sensory-feedback strategies and identify which aspects of VR-based embodiment realistically transfer when accounting for hardware limits, sensor variability, and cognitive load. Ultimately, the workshop aims to articulate a focused research agenda connecting VR-based insights to feasible wearable robotics implementations, enabling future work on augmenting the human body with new parts and capabilities.

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CCS Concepts

• **Human-centered computing** → *Virtual reality*; *Interaction paradigms*.

Keywords

Embodied interaction, human augmentation, VR, wearable robotics

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1 Motivation

Over the past decades, research in human–computer interaction (HCI) and human–robot interaction (HRI) has shown that people can experience ownership and agency over virtual bodies in virtual reality, even when those bodies do not match human morphology [2, 6, 7]. Beyond VR, researchers in robotics and neuroscience have sought to extend the human body by developing supernumerary robotic limbs (SRLs), such as wearable third arms or robotic tails, that attach to the body [1, 3, 5, 8, 10, 11]. These two domains, virtual embodiment in XR and on-body augmentation with wearable robotics, share the goal of extending human morphology and expanding human capabilities.

A substantial gap remains, however, because the user experience in virtual environments is not the same as in physical settings. Even for an identical function, such as a tail, matched control schemes and feedback can still yield different subjective and behavioral outcomes in VR versus wearable robotics. Our field still lacks a detailed account of when ownership and agency cultivated in VR predict comparable experiences during actual use of a wearable robotic system, and under what conditions those effects break down.

To make body augmentation viable at scale, we need interaction techniques that make augmented parts feel and move as if they were the user's own in both virtual environments and when working with wearable robotics. Progress depends on methods and reporting practices that let research findings travel between simulation and hardware rather than stall at their boundaries.

Recent advances in motion tracking and sensing have enabled a surge of studies on virtual-body embodiment. These range from investigations of sensory-feedback strategies that foster immersion and ownership with virtual avatars [7, 9] to simulations that probe interaction techniques for prospective extra limbs [4, 12]. However, translating the lessons learned on control mappings and sensory-feedback strategies into concrete design choices for wearable robotics remains barely explored. VR's controlled and iterative simulation can de-risk early stage development before hardware is built: researchers can pre-test action-to-function mappings, compare alternative feedback schedules and modalities, and surface likely failure modes without additional cost. Closer coupling between virtual environments and wearable robotics around the shared goal of augmented body parts can shorten design cycles, yield reusable interaction artifacts, and clarify practical pathways for sim-to-real transfer.

This workshop takes up that agenda. First, we will ideate interaction approaches in VR that can foster embodiment and adaptation for augmented body parts. Second, we will examine what must be considered to apply or adapt those approaches to wearable robotics, including constraints in sensing, actuation, comfort, and onboarding. Through iterative ideation and moderated discussion, we aim to explore the design space of control mappings and sensory-feedback strategies for a variety of extended body parts, and to specify how insights from those simulations should be packaged and adapted for wearable robotics implementations.

1.1 Theme 1: How can we foster embodiment and adaptation with virtually augmented bodies?

We will brainstorm how users can naturally adapt to virtually augmented body parts (for example, wings, tails, or a third hand) and how specific design choices can strengthen body ownership and embodiment. For example:

- How can we characterize the design space for embodiment and body ownership, including control mapping choices, feedback modalities, and on-body locations?
- How can we design training and onboarding protocols that extend plasticity without fatigue or overtrust?
- Where are the limits of human plasticity for augmented body parts, and how far can morphology deviate from the human template (for example, shape, kinematics, degrees of freedom) before ownership and skilled control degrade? What training or design factors expand this tolerance?

1.2 Theme 2: How can we bridge embodiment in VR to robotic use?

We will discuss how strategies for enhancing embodiment and adaptation, developed while augmenting body parts in virtual environments, can be translated into practical and reusable practices for implementations with wearable robotics. For example:

- Which VR-derived strategies for enhancing embodiment and adaptation transfer most reliably to wearable robotics, and how can we package them as reusable templates (for example, mapping grammars, sensory-feedback recipes, onboarding playbooks)?
- What minimal evidence gathered in VR best predicts success with hardware, and which indicators or short transfer tasks should groups report to make results comparable across wearable systems?
- How should we capture and hand off artifacts from VR (e.g., avatar logs, interaction traces, mapping tables, controller parameters) so that robotics developers can reuse them across different morphologies and kinematics, while ensuring feedback and timing properties stay realistic?

2 Pre-Workshop Plans

2.1 Target Audience & Recruitment

The organizers will hold regular teleconferences to align goals, deliverables, and activities. We will distribute a call for participation via the workshop website, mailing lists, and social media, and invite researchers across **embodied interaction, human augmentation, XR, wearable robotics, haptics, multimodal sensing, neuroscience**. Recruitment will be centered on the workshop website, which will host the call, organizer information, the timeline, submission instructions and templates, an FAQ (including accessibility notes), and contact details. In parallel, we are compiling a list of potential attendees from academia and industry (XR platforms, wearable/haptics startups, rehabilitation robotics, and labs working on embodiment) and will conduct targeted outreach. Promotion will run in three waves (launch, mid-cycle reminder, and a final reminder one week before the deadline), with short updates posted to social channels and relevant mailing lists. We aim to recruit approximately **20 participants** who submit position or demo/video papers explicitly linked to **Themes 1–2** (minimum 10 registrants as per CHI guidance).

2.2 Paper Submission & Review Process

We invite position papers (up to 4 pages) and demo/video papers (up to 2 pages with a short video), following CHI publication formats. Submissions will be received through the link on the website and each will be reviewed by at least two organizers for relevance to **Themes 1–2**, clarity of contribution, and fit with the workshop's goals. Conflicts of interest will be managed by reassignment to non-conflicted reviewers, and acceptance decisions will balance perspectives across XR, HCI/HRI, and wearable robotics, as well as career stage and institutional diversity. A provisional timeline is: website launch and CFP announcement (week 0), rolling Q&A via the website (weeks 0–8), submission deadline (week 6), notifications (week 8), and sharing of pre-workshop materials among accepted participants (week 9). Accepted position papers will be shared in brief in-group introductions and referenced during the group activities; demo/video papers will be featured during the showcase or as embedded references in activities.

2.3 Pre-Workshop Materials

To seed more diverse ideas within our topic, we will share two resources via the workshop website upon notification:

- **Shared Miro board.** Two frames will be provided for early contributions: (i) augmented body parts beyond commonly cited SRLs (for example, wings, tails, extra eyes, internal or proprioceptive augmentations); (ii) control and sensory-feedback ideas to explore in Group Activity 1. Each accepted participant is invited to add at least one short card per frame.
- **Reading pool.** A concise starter list on virtual embodiment and wearable robotics, plus an open slot where participants may add one representative paper or a short video from their own work to support discussion.

Links will be distributed with acceptance notifications, and contributions will remain open until the workshop date.

3 Workshop Structure

This long-format workshop uses two 90-minute sessions with a short break in between. Activities follow a streamlined flow: *introduction → keynote → in-group ice breaking with brief position presentations → group activity 1 / break / group activity 2 → presentations & wrap-up.*

3.1 Session A (90 min): Introduction, Keynote, Ice Breaking, Group Activity 1

Introduction (5 min). Objectives, ground rules, and shared outputs.
Keynote (30 min). Big-picture synthesis on *Embodiment Across Realities* aligned to Themes 1–2.
In-group ice breaking (15 min). At each table, participants give a 1–2 minute brief of their position paper and post one claim plus one question tagged to Theme 1 or Theme 2.
Group activity 1 (40 min). Teams of 3–4 receive a random extended body part. They decide where it attaches, how it is controlled using existing movements or gestures, what sensory feedback is provided, and which technical elements are required. Ideas are sketched on a mapping canvas. Teams alternate a quick one-slide share-back within the block.

3.2 Session B (90 min): Group Activity 2, Presentations, Wrap-Up

Group activity 2 (50 min). Teams exchange concepts and further develop each other's designs. They consider how, if implemented as wearable robotics, the concept would address sim-to-real issues such as consistent sensory feedback across VR and physical devices, differences in human perception between simulated and real environments, and hardware-aware constraints when prototyping in VR. Additional considerations include minimal calibration needs, realistic sensing and feedback modeling, latency and temporal alignment, safety and comfort, and cognitive aspects such as attention and load. Deliverables are a refined concept sheet and a sim-to-real checklist.
Presentations (35 min). Alternating team presentations with short Q&A.
Wrap-up (5 min). Consolidate insights, align on next steps, and ingest artifacts into a shared repository.

4 Post-Workshop Activities

We will curate and publish the outputs on the workshop website (i) a compact set of mapping and feedback pattern scenarios from Theme 1, (ii) a minimal sim-to-real transfer checklist from Theme 2, and (iii) a top-ten list of shared research questions. We will invite contributors to co-author a short workshop report and maintain a mailing list for follow-up collaboration, including optional data and template sharing for future replications.

To share the outcomes of the workshop with the HCI community and a wider audience, we plan to submit articles (e.g., ACM Interactions) that discuss the current and future expected directions for the embodiment of virtual and robotic augmented body parts. We will also encourage participants to further develop their workshop submissions and to possibly collaborate with other workshop participants. To maintain on-going communication, we plan to open up a Discord group initially for workshop participants to share materials, news, and updates before and after the workshop. After the workshop, we will plan the next version of this workshop at relevant conference venues, through which we plan to expand the Discord group with researchers of diverse backgrounds.

Table 1: Workshop schedule at a glance (two 90-minute sessions with a short break).

Session	Time	Segment	Activity / Description
A (90')	00:00–00:05	Introduction	Objectives, norms, and shared outputs.
	00:05–00:35	Keynote	Big-picture synthesis aligned to Themes 1–2.
	00:35–00:50	In-group ice breaking	At each table, 1–2 minutes per person to briefly present their position paper and name one open question (tagged T1 or T2).
	00:50–01:30	Group activity 1	*Theme 1.* Teams of 3–4 are assigned a random extended body part. Ideate where it attaches, how to control it, what sensory feedback to provide, and which technical elements are needed. Capture ideas on a provided canvas. Within this block, groups rotate short share-backs so everyone hears 1 slide per team.
	Break (10–15 minutes)		
B (90')	00:00–00:50	Group activity 2	*Theme 2.* Swap concepts between teams and refine each other's designs. Discuss sim-to-real considerations such as aligning sensory feedback between VR and physical devices, accounting for perceptual differences across environments, and constraining VR prototypes to realistic hardware limits. Consider user cognition and workload to support reliable transfer to wearable use. Produce a refined concept sheet and a first-pass sim-to-real checklist.
	00:50–01:25	Presentations	Alternating short presentations: 4 minutes per team, 2 minutes Q&A.
	01:25–01:30	Wrap-up	Consolidate insights and next steps; collect all artifacts into a shared repository.

5 Organizers

To explore how insights can bridge the results of the VR-based studies to real wearable robotics, we formed an organizing team with diverse disciplinary backgrounds and hands-on experience in HCI/HRI regarding VR, wearable robotics, haptics, and multimodal sensing. This combination supports a focused, cross-domain conversation on augmented body parts.

HyeonBeom Yi, Ph.D., is a researcher at the Electronics and Telecommunications Research Institute (ETRI). He is working at the intersection of embodied interaction, XR, and wearable haptics. His research explores end-to-end systems that translate multimodal information into expressive on-body haptic actuation, with a focus on understanding user experience through iterative design. He is particularly interested in how novel multimodal feedback can bridge physical environments with digital content.

Myung Jin (MJ) Kim is a Postdoctoral Researcher at the Electronics and Telecommunications Research Institute (ETRI). His research interest is in HCI, especially in multimodal perception, extended reality (XR) interfaces, and adaptive systems that enhance engagement and usability in immersive environments. His work investigates how feedback is perceived and integrated across modalities to support more intuitive and embodied user experiences.

Seungwoo Je is an Assistant Professor at the School of Design at Southern University of Science and Technology (SUSTech). His research interests include Human–Computer Interaction, with a particular focus on VR/AR, haptics, and tangible interfaces. He is particularly interested in designing multisensory interactions and novel hardware systems that bridge digital and physical experiences.

Seungjae Oh is an Assistant Professor in the Department of Software Convergence at Kyung Hee University. His research has focused on the design and development of novel sensing techniques, haptic output devices, and AI-powered interactive applications. His work in Human–Computer Interaction emphasizes systematic methodologies to seamlessly integrate input and output modalities.

Shuto Takashita is a Ph.D. student at the Information Somatics Lab at the University of Tokyo. His research interests include avatars with non-human morphologies, embodied cognition, extended reality (XR), and human augmentation. His work explores how mediation between human and non-human forms can extend the limits of human plasticity. He is also interested in avatar cultures within social VR spaces.

Marie Muehlhaus is a Ph.D. student at the Human-Computer Interaction Lab at Saarland University. Her research focuses on wearable robotics, body actuation and body-based interaction. She explores how to design seamless interactions between humans and wearable robots, combining low-fidelity prototyping and empirical methods. She is also interested in how wearable robots can be used to enhance avatar embodiment in VR.

Hongyu Zhou is a Ph.D. student in the School of Computer Science at the University of Sydney. Her work sits at the intersection of embodied interaction, virtual/extended reality (VR/XR), and human–robot augmentation. She studies how multiple people (and semi-autonomous supernumerary limbs) coordinate within a shared avatar or shared space, focusing on teleoperation, perspective, attention management, safety/proxemics, and user experience.

Eyal Ofek is a professor and Chair of Computer Science at the University of Birmingham, UK. His work spans computer vision and sensing for Human–Computer Interaction and Mixed Reality, haptic rendering and perception, robotics, and wearable sensing. He studies sensory augmentation across audio-visual and haptic modalities to improve collaboration, productivity, and inclusion.

Andrea Bianchi is an Associate Professor in the Department of Industrial Design and an Adjunct Professor in the School of Computing at KAIST. He researches in the field of Human-Computer Interaction, focusing on building tools for creativity support that blend physical and digital elements, such as toolkits, physical computing, fabrication, as well as hardware systems for body augmentation.

6 Call for Participation

This long-format CHI 2026 workshop gathers researchers and practitioners in embodied interaction, VR, wearable robotics, haptics, multimodal sensing, and neuroscience to connect outcomes across virtual embodiment and on-body augmentation. We will focus on two questions: (1) how to foster embodiment and adaptation with augmented body parts, and (2) how to bridge virtual embodiment in VR to effective use with wearable robotics. The program includes a keynote, brief in-group position shares, and two hands-on group activities: first, teams ideate control mappings and sensory-feedback strategies for randomly assigned extended body parts; second, teams swap and further develop those concepts toward practical considerations for implementation with wearable robotics. We invite position papers (2–4 pages) or demo/video papers (1–2 pages + video) using the CHI publication formats; details and dates will be announced on the workshop website: augmented-body-parts . Submissions will be reviewed by the organizers for relevance and quality. At least one author of each accepted submission must attend, and all participants must register for the workshop (and the conference as required). We expect around 20 participants (minimum 10). Accepted materials will be highlighted on the workshop website; we plan a concise post-workshop report and will share the results.

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