Inbody Interactions

Suranga Nanayakkara*
Augmented Human Lab, National University of Singapore
Singapore, Singapore
suranga@ahlab.org

Masahiko Inami
The University of Tokyo
Tokyo, Japan
inami@inami.info

Kai Kunze
Keio University
Keio, Japan
kai.kunze@gmail.com

Elizabeth Churchill
Mohamed Bin Zayed University of Artificial Intelligence
Abu Dhabi, United Arab Emirates
elizabeth.churchill@mbzuai.ac.ae

Kanyu Chen
Graduate School of Media Design, Keio Universitty
Keio, Japan
cady.cky@kmd.keio.ac.jp

Danyang Peng
Graduate School of Media Design, Keio Universitty
Keio, Japan
pengdanyang111@gmail.com

Prasanth Sasikumar
Augmented Human Lab, National University of Singapore
Singapore, Singapore
prasath@ahlab.org

Yize Wei
Augmented Human Lab, National University of Singapore
Singapore, Singapore
yize@ahlab.org

Mia Huong Nguyen
Augmented Human Lab, National University of Singapore
Singapore, Singapore
mia@ahlab.org

Abstract

An emerging paradigm in human-computer interaction addresses systems that bidirectionally sense and influence internal physiological states (cardiac rhythms, respiratory patterns, metabolic activity, and gastric function). Unlike traditional interfaces that respond to voluntary user actions, these interoceptive systems engage with signals users often cannot directly perceive or control, creating closed-loop interactions between computing systems and inbody states. Such systems can modulate autonomic responses, guide breathing patterns, or influence metabolic states through coordinated sensory stimulation, with applications ranging from stress management to emotion regulation.

While recent research demonstrates technical feasibility across individual modalities (cardiac biofeedback through haptic stimulation, respiratory guidance through thermal cues, metabolic monitoring through continuous sensing) fundamental questions remain unaddressed: How do we design interaction paradigms for internal states? What computational frameworks enable real-time adaptation of interventions to individual physiological responses? How do we coordinate multiple organ systems within unified interaction architectures? What ethical boundaries govern systems that influence autonomic function?

This workshop brings together researchers from human-computer interaction, affective computing, physiological psychology, biosignal processing, and ethics to develop systematic frameworks for interoceptive manipulation, map the design space for closed-loop internal state interfaces, establish ethical guidelines for bidirectional physiological computing, and examine applications in emotion regulation while preserving user agency and bodily autonomy.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**; **Accessibility**.

Keywords

Inbody Interaction, Augmented Body, Interaction Design, Human Computer Integration

ACM Reference Format:
Suranga Nanayakkara, Masahiko Inami, Kai Kunze, Elizabeth Churchill, Kanyu Chen, Danyang Peng, Prasanth Sasikumar, Yize Wei, and Mia Huong Nguyen. 2026. Inbody Interactions. In *The Augmented Humans International Conference 2026 (AHs 2026), March 16–19, 2026, Okinawa, Japan.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3795011.3797157

1 Introduction

Consider physiological responses during a stressful presentation: racing heart, rapid shallow breathing, butterflies in the stomach. You experienced these responses but couldn't control them; they just happened to you. Now imagine a different scenario: You feel your heart accelerating, but your smartwatch delivers precisely timed haptic pulses that gradually slow your perceived heart rate. Your breathing steadies as thermal cues guide you toward patterns known to reduce autonomic arousal. Within minutes, the physiological cascade of anxiety begins to reverse; not through willpower or breathing exercises alone, but through computational systems that directly engage with your internal organ states. Each of these interventions has been demonstrated in laboratory settings with measurable effects on physiological state and subjective emotional experience. Recent advances demonstrate the possibility of deliberately modulating such responses, for example: calming cardiac rhythms through synchronized haptic feedback [3, 10], guiding respiratory patterns through thermal or vibrotactile cues [1, 4, 9],

*Corresponding Author.

AHs 2026, Okinawa, Japan

ACM ISBN 979-8-4007-2351-3/26/03
https://doi.org/10.1145/3795011.3797157

or influencing gastric interoception with haptic feedback [6]. Each approach shows measurable effects on both physiological state and subjective emotional experience.

This represents a fundamental shift in human-computer interaction: from passive monitoring of physiological signals toward active, bidirectional manipulation of internal states. We can now design closed-loop systems that sense cardiac rhythms, provide interventions to influence those rhythms, and measure resulting changes in both physiological patterns and psychological states [3]. Similar capabilities exist for respiratory guidance, metabolic modulation, and potentially gastric function [5, 6].

2 Research Gap and Motivation

Workshops on cognitive sensing and affective computing have addressed inference of psychological states from physiological signals, but primarily in one direction (sensing without manipulation). What remains absent is systematic investigation of bidirectional interaction with internal organ states, not external muscles or passive sensing, but closed-loop computational engagement with cardiac, respiratory, metabolic, and gastric function.

What distinguishes this workshop from traditional biofeedback is the move from passive sensing to active manipulation, from one-way monitoring to closed-loop control, and from single-modality interventions to integrated approaches engaging multiple interoceptive pathways simultaneously. Rather than merely inferring user states from bodily signals, we design interaction paradigms that bidirectionally engage with internal states.

This is fundamentally an **interaction design and computational challenge**, not a medical or purely physiological one. Key questions include:

- How do we design interaction paradigms for signals users often cannot directly perceive or voluntarily control?
- What computational frameworks enable real-time adaptation and personalization?
- How do we create feedback loops that respect user agency while effectively modulating internal states?
- What interface metaphors are appropriate for representing and manipulating interoceptive information?

Neuroscience evidence demonstrates that internal bodily states don't merely reflect emotions but actively constitute them [2, 7, 8]. Interoceptive signals from the heart, respiratory system, gut, and metabolic processes contribute to the subjective experience of affect [8]. This suggests that systems capable of modulating these internal states might serve as tools for emotion regulation—moving beyond emotion recognition toward emotion interaction. This positions inbody interactions as advancing affective computing's evolution from passive inference to active support for emotional well-being .

The timing is now opportune for several reasons. Sensor technologies have matured to enable non-invasive measurement of cardiac electrical activity, breathing patterns, continuous glucose levels, and gastric electrical rhythms with sufficient precision for closed-loop control. Actuation methods have expanded beyond traditional visual feedback to include haptic cardiac biofeedback, thermal respiratory guidance, transcutaneous vagus nerve stimulation, and olfactory triggering. Machine learning approaches can personalize interventions based on individual physiological signatures. The convergence of these capabilities with growing scientific understanding of interoception's role in cognition and emotion creates the opportunity to move from isolated experiments toward systematic frameworks.

Our proposed workshop addresses closed-loop bidirectional inbody interactions focused on physiological states, not external motor control and not only passive sensing for emotion recognition. Our scope encompasses cardiac, respiratory, metabolic, and gastric systems as primary interoceptive modalities. Brain stimulation is explicitly excluded; it constitutes a separate research community already well-covered in other seminars.

We call for submissions from expertise spanning HCI researchers exploring interaction paradigms, affective computing experts connecting internal states to emotion, biosignal processing specialists developing sensing methods, machine learning researchers creating adaptive algorithms, physiological psychologists understanding interoceptive mechanisms, and ethicists establishing appropriate boundaries.

We will solicit two main categories of submissions: Participants will be invited to submit (1) position statements of up to 2 pages OR (2) 1-page write-up describing an interactive research prototype they would like to demonstrate at the workshop.

3 Content of Workshop

We intend to hold a half-day workshop. We expect about 10- position papers and demonstrations. The workshop will consist of three components: (i) lightning talk presentations, (ii) breakout group discussion and (iii) synthesis of the discussion & plan beyond the workshop. In terms of resources, we would need a room with a few round tables to facilitate breakout discussions, a projector with a standard AV system to run the lightning talks, power outlets to charge computers, flip charts, post-it notes, and whiteboard markers. The workshop will run as follows:

- **9:30-9:45**: Introduction & Welcome
- **9:45-11.00**: Lightning Talks & Demos (include a tea break of 15 mins)
- **11.00-12:00**: Break out group discussion
- **12:00-12:30**: Sharing of group discussions, Next steps & Closing remarks
- **12:30-13:30**: Lunch & Networking

4 Goals and Outcomes

The goal of the workshop is to provide a platform to brainstorm, debate and discuss closed-loop interoceptive manipulation as a coherent research area with systematic frameworks, shared methods, and ethical guidelines. We focus on four goals:

Goal 1: Map the Interaction Design Space for Inbody Interaction. Through structured breakout sessions, we will systematically map dimensions along which interoceptive manipulation systems vary: intervention modality (electrical, mechanical, thermal, chemosensory, cross-modal), target organ system (cardiac, respiratory, metabolic, gastric), temporal patterns (continuous, pulsed, adaptive), user awareness levels (explicit versus subliminal), and degree of user control (automatic versus user-directed). We will identify unexplored combinations and position existing work within this space.

Goal 2: Draft Ethics Charter for Inbody Interaction Research. We will conduct an ethics roundtable examining risk scenarios (misinterpretation of physiological data, over-reliance on automated interventions, privacy concerns with "deep data"), mitigation patterns, and boundaries between acceptable and problematic manipulation across different contexts (clinical, workplace, consumer).
Goal 3: Specify Minimal Viable Manipulation Toolkit for Multi-Lab Research. To enable research continuation after the seminar, we will specify a practical toolkit architecture supporting experimentation with multiple manipulation modalities—accessible tVNS devices, haptic cardiac biofeedback systems, thermal actuation methods, respiratory guidance platforms, and software frameworks for implementing closed-loop control.
Goal 4: Establish Research Agenda and Foster Collaborations. We will identify key technical challenges (cross-modal interactions, temporal dynamics, individual differences), open scientific questions, and opportunities for collaborative projects addressing these challenges.

The proceedings of the workshop will be made available via the workshop webpage (https://inbody.ahlab.org/). Together with interested attendees, the discussion of the workshop will be extended as a journal paper. One potential target journal would be the Foundations and Trends in Human-Computer Interaction.

5 Recruitment & Reviewing

We will advertise the workshop in several research communities, including CHI, UIST, ASSETS, Augmented Humans, and MobileHCI, via our research network. We also plan to promote the workshop through the workshop website and through social media. We expect around 15-20 submissions. These submissions will be reviewed by an organising committee member and discussed in a committee meeting. Ten submissions will be selected based on 1) relevance to the workshop theme; and 2) ability to foster discussion at the workshop. The total number of workshop attendees on site will be around 20.

6 Organizer Biographies

Suranga Nanayakkara is an Associate Professor at Department of Computer Science, School of Computing at National University of Singapore. He founded the "Augmented Human Lab" to explore ways of designing intelligent human-computer interfaces that extend the limits of our perceptual and cognitive capabilities.
Masahiko Inami is a Professor at the Research Center for Advanced Science and Technology, University of Tokyo. His research interest is in human I/O enhancement technologies/bioengineering, HCI and robotics.
Kai Kunze is a Professor at the Graduate School of Media Design, Keio University. He has over fifteen years of experience in the Wearable Computing and serves as the co-chair of the International Wearable Computing Academic Research Community.
Kanyu Chen is a PhD student, at the Keio University in Tokyo, Japan. Her current research focuses on applying physiological sensing technology to voice/vocal training and emotion regulation. She is dedicated to exploring innovative technologies of wearable and perception computing in embodied skill training, mental health and human augmentation.
Danyang Peng is a PhD student at the Graduate School of Media Design, Keio University. Her work focuses on multimodal interaction, immersive XR experiences, and physiological sensing to support mental well-being and self-reflection.
Elizabeth Churchill is the Department Chair and Professor of Human-Computer Interaction at The Mohamed Bin Zayed University of Artificial Intelligence. She is an applied social scientist, interactive technology designer and social communications researcher. She has a background in psychology (neuro, experimental, cognitive and social), AI, and cognitive science. For the past 20+ years, she has drawn on social, computer, engineering and data sciences to create innovative end-user applications and services.
Prasanth Sasikumar is a Postdoctoral fellow at the Augmented Human Lab, National University of Singapore. He is researching on novel extended reality technologies that enhance remote collaboration to advance human potential.
Yize Wei is a PhD student at the Augmented Human Lab, National University of Singapore. Her research interest is situated in the intersection of Accessibility, Human-Robot Interaction, and Human-AI Interaction. She is particularly interested in how robots (e.g., drones) can assist blind users as novel assistive solutions.
Mia Huong Nguyen is a PhD student at the Augmented Human Lab, National University of Singapore. She is interested in the human mind, emotion, and artificial intelligence. Her research focuses on designing technologies that expand people's affective capacity to enhance their emotional resilience and well-being.

References

[1] Stephanie Balters, Matthew L. Mauriello, So Yeon Park, James A. Landay, and Pablo E. Paredes. 2020. Calm Commute: Guided Slow Breathing for Daily Stress Management in Drivers. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 1 (March 2020), 1–19. https://doi.org/10.1145/3380998

[2] Lisa Feldman Barrett. 2017. The theory of constructed emotion: an active inference account of interoception and categorization. *Social Cognitive and Affective Neuroscience* (2017), nsw154. https://doi.org/10.1093/scan/nsw154

[3] Jean Costa, François Guimbretière, Malte F. Jung, and Tanzeem Choudhury. 2019. BoostMeUp: Improving Cognitive Performance in the Moment by Unobtrusively Regulating Emotions with a Smartwatch. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 3, 2 (June 2019), 1–23. https://doi.org/10.1145/3328911

[4] Pardis Miri, Emily Jusuf, Andero Uusberg, Horia Margarit, Robert Flory, Katherine Isbister, Keith Marzullo, and James J. Gross. 2020. Evaluating a Personalizable, Inconspicuous Vibrotactile(PIV) Breathing Pacer for In-the-Moment Affect Regulation. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–12. https://doi.org/10.1145/3313831.3376757

[5] Mia Huong Nguyen, Moritz Alexander Messerschmidt, Chitralekha Gupta, and Suranga Nanayakkara. 2025. GutIO: Toward Sensing and Inducing Gut Feelings with Abdominal Sounds. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3706599.3719826

[6] Mia Huong Nguyen, Moritz Alexander Messerschmidt, Jochen Huber, and Suranga Nanayakkara. 2026. VisceroHaptics: Investigating the Effects of Gut-based Audio-Haptic Feedback on Gastric Feelings and Gastric Interoceptive Behaviours. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '26)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3772318.3790268

[7] Anil K. Seth and Karl J. Friston. 2016. Active interoceptive inference and the emotional brain. *Philosophical Transactions of the Royal Society B: Biological Sciences* 371, 1708 (Nov. 2016), 20160007. https://doi.org/10.1098/rstb.2016.0007

[8] Clare Shaffer, Christiana Westlin, Karen S. Quigley, Susan Whitfield-Gabrieli, and Lisa Feldman Barrett. 2022. Allostasis, Action, and Affect in Depression: Insights from the Theory of Constructed Emotion. *Annual Review of Clinical Psychology* 18, 1 (2022), 553–580. https://doi.org/10.1146/annurev-clinpsy-081219-115627 _eprint: https://doi.org/10.1146/annurev-clinpsy-081219-115627.

[9] Muhammad Umair, Corina Sas, Niaz Chalabianloo, and Cem Ersoy. 2021. Exploring Personalized Vibrotactile and Thermal Patterns for Affect Regulation. In *Proceedings of the 2021 ACM Designing Interactive Systems Conference* (Virtual Event, USA) *(DIS '21)*. Association for Computing Machinery, New York, NY, USA, 891–906. https://doi.org/10.1145/3461778.3462042

[10] Mingdi Xu, Takeshi Tachibana, Nana Suzuki, Eiichi Hoshino, Yuri Terasawa, Norihisa Miki, and Yasuyo Minagawa. 2021. The effect of haptic stimulation simulating heartbeats on the regulation of physiological responses and prosocial behavior under stress: The influence of interoceptive accuracy. *Biological Psychology* 164 (2021), 108172. https://doi.org/10.1016/j.biopsycho.2021.108172