Extended Nonverbal Expressions in Hybrid Robots with Physical and AR-Based Presentations

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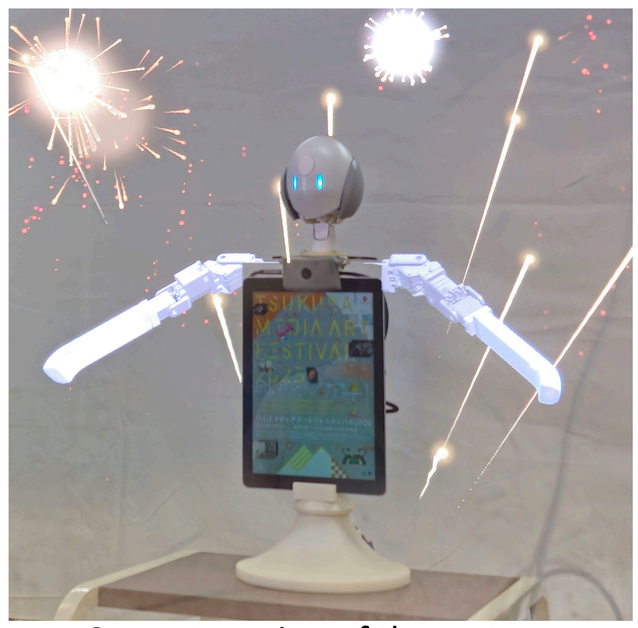
Abstract: Robotic embodiment and virtual embodiment have been proposed as methods for conveying nonverbal expressions. Despite their potential, methods using physical robots often encounter high implementation costs, while AR devices face limitations due to their restricted field of view (FoV), which results in the loss of peripheral information.

This study introduces a hybrid robot system integrating physical robotic parts with optical see-through AR devices for AR-based presentations. The research defines extended nonverbal expressions to overcome robots' physical limitations, aiming to establish design guidelines for hybrid robots in remote communication. The study proposes a design space organizing hybrid robots' configurations and expressive capabilities based on communication purposes. A prototype system was developed to demonstrate the feasibility of incorporating extended nonverbal expressions into hybrid robot designs, showcasing potential real-world applications. This approach offers a promising solution to enhance nonverbal communication in remote settings, bridging the gap between physical and virtual interactions.



Current version of the system
(updated from the paper version)

CHALLENGES

Robotic Embodiment: High costs for system design, implementation, and maintenance of physical components.

Virtual Embodiment (AR): Restricted Field of View (FoV) leads to the loss of peripheral information.

HYBRID EMBODIMENT

Integrating physical robotic parts and AR presentation by optical see-through AR devices to enhance expressiveness. Within the AR device's FOV,AR extends the physical robot's expressive capabilities (Fig.1-a). Beyond the AR device's FOV, the physical robot's persistent presence compensates for peripheral vision limitations(Fig. 1-b).

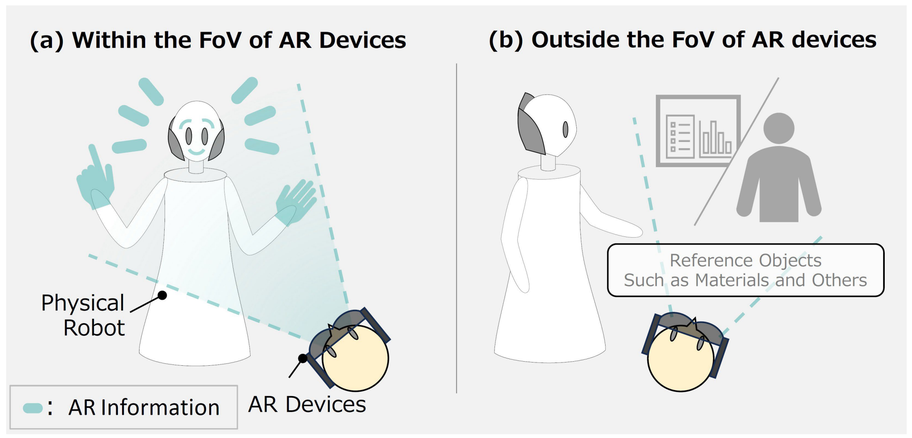


Fig. 1. Concept of the Hybrid Robot System.

EXTENDED NONVERBAL EXPRESSIONS

With the hybrid configuration, it is also possible to extend the robot's expressive capabilities. We propose two approaches:

- Replicating nonverbal expressions that are difficult to implement physically, such as facial expressions or hand gestures, using AR (Fig. 2-a).
- Enhancing nonverbal expressions that go beyond physical constraints, such as extending arms during pointing, highlighting gaze areas, or displaying emotions through aura effects (Fig. 2-b).

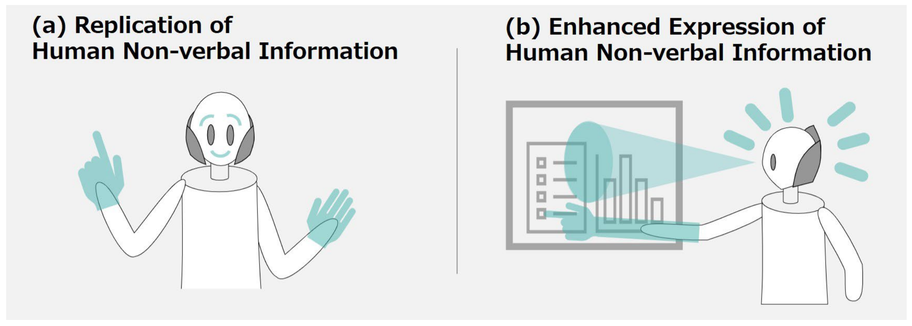


Fig. 2. Approaches for extended nonverbal expressions.

DESIGN SPACE

The design space for extended nonverbal expressions is shown in Fig. 3.

The vertical axis represents categories of nonverbal information: *reference*, *appearance/expressions*, and *others*.

The horizontal axis represents types of AR-based extensions: *information provision*, *information refinement*, and *enhanced expression*.

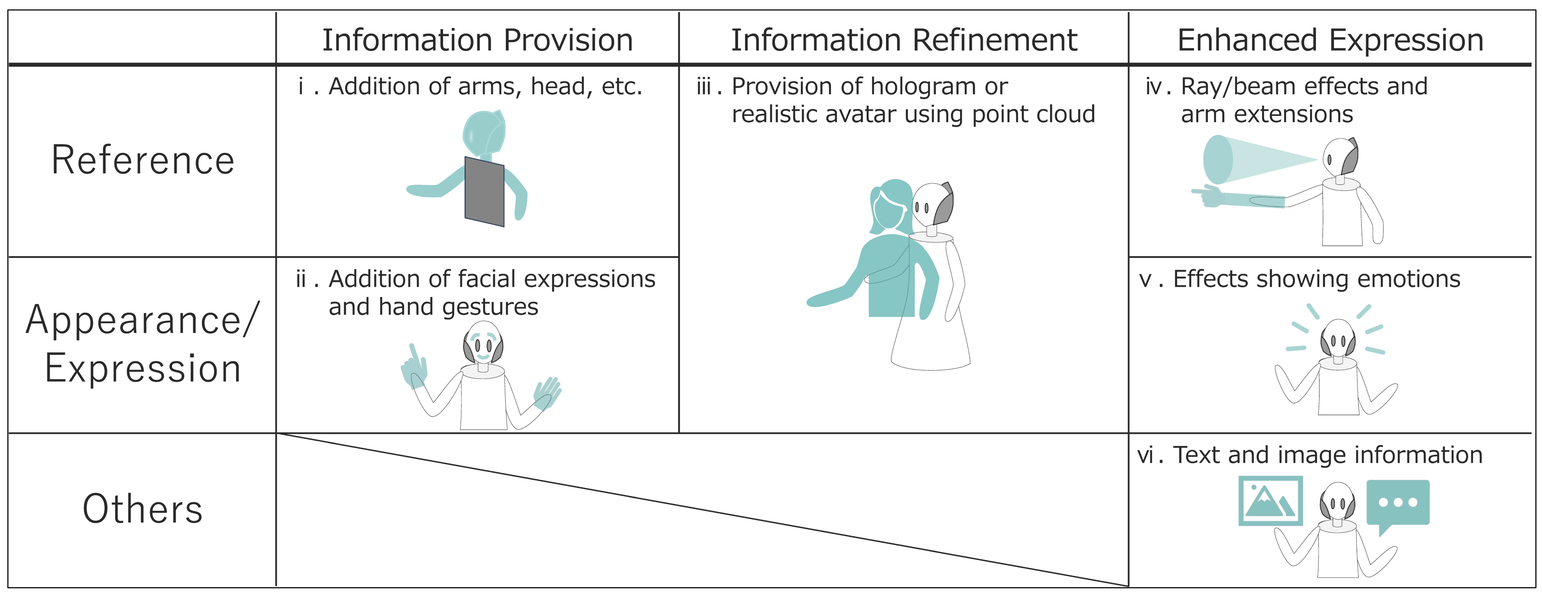


Fig. 3. Design space for extended nonverbal expressions.

PROTOTYPE SYSTEM

The prototype system consists of a physical robot, HoloLens 2, AR control PC, and remote control PC (Fig. 4).

Currently, the system supports adding arms and head, facial expressions and hand gestures, visualizing pointing directions with rays, and showing emotion-related aura (Fig. 5).

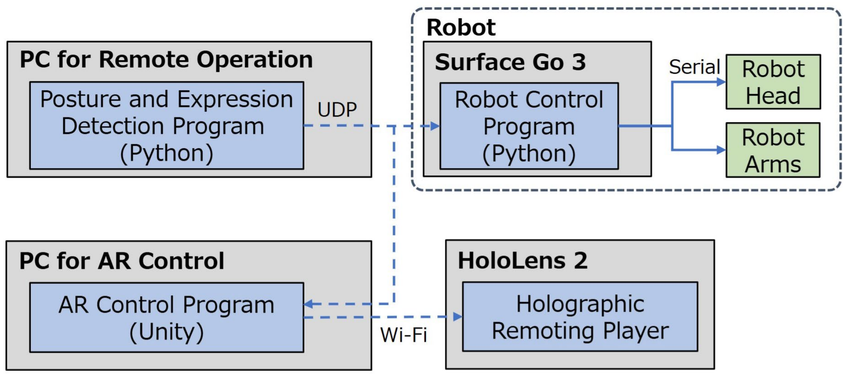


Fig. 4. System configuration.

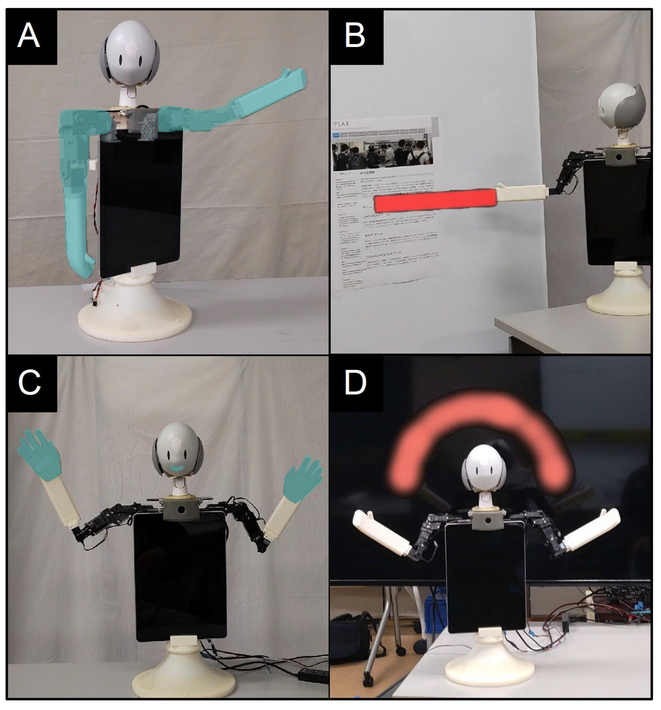


Fig. 5. Features of prototype system.

CONCLUSION AND FUTURE WORK

This study defined the concept and design space of **extended nonverbal expressions** for **hybrid robots** and implemented a prototype system. As future work, we plan to implement additional features (e.g., point cloud holograms) and conduct comparative experiments to evaluate the effectiveness of the extended nonverbal expressions in hybrid robots against AR-only and physical-only conditions.