# TeleAware Robot: Designing Awareness-augmented Telepresence Robot for Remote Collaborative Locomotion

Jiangtao Gong[1], Ruyi Li[1] and Qianying Wang[2]

***Abstract*— Telepresence robots enable remote navigation and shared experiences, but lack sufficient environmental and partner awareness. We introduce an awareness framework for collaborative locomotion between onsite and remote users. Based on an observational study, we developed TeleAware robot with awareness-enhancing techniques. A controlled experiment showed TeleAware robot reduced workload, improved social proximity, mutual awareness, and social presence compared to standard robots. We discuss mobility impact, user roles, and future design insights for awareness-enhancing telepresence systems facilitating collaborative locomotion.**

## I. INTRODUCTION

Remote collaboration is increasingly common in various activities, often with moving participants [1], [2], [3]. In physical contexts, remote collaborative locomotion is used in scenarios like conference attendance [4] and shop exploration [5]. Co-located walkers maintain awareness through subconscious locomotion [6], engaging in actions that support collaborative navigation and create a shared experience. However, collaborative locomotion with telepresence robots presents challenges [7], [5], [4]. Remote operators often lack sufficient awareness of spatial proximity and on-site social interactions.

This work aims to enhance social and environmental awareness between local and remote users in telepresence robot interactions. We conducted observational studies of in-person exhibition visits, developed a design space for user-partner-environment awareness, and implemented features in a "TeleAware Robot." Through experiments, we compared its performance against a standard telepresence robot. Our contributions include: i) An awareness framework for collaborative locomotion. ii) Four design goals and features to enhance telepresence robot awareness. iii) Development and testing of the TeleAware Robot. iv) Insights on awareness-enhancing features' effects on user roles, interaction, and presence.

## II. OBSERVATIONAL STUDY

We conducted an observational study of dyads during collaborative exhibition viewing to inform telepresence robot design. 38 participants (19 pairs) were recruited on-site, informed of the study's objective, and observed for ten minutes via video recording. The pilot study used qualitative analysis, inspired by Kuflik and Dim's categorization [8].

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### A. Findings

Based on our observations, we derived the "User-Partner-Environment" framework and analyzed awareness needs and behaviors within this framework.

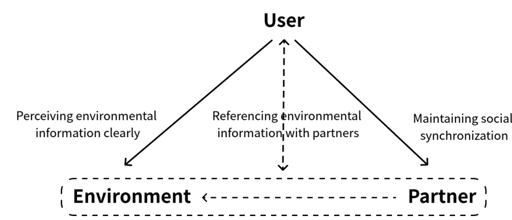


Fig. 1. The "User-Partner-Environment" framework in collaborative locomotion, encompassing User-Environment (spatial awareness), User-Partner (social awareness), and User-(Partner-Environment) (situational awareness) relationships.

*1) User-Environment:* Viewers exhibited strong spatial awareness, primarily relying on visual perception (86.17% of time) to process environmental information. This led to our first design goal:

> **Design Goal 1: Enhance the environmental visibility of local spaces for remote users to improve spatial awareness.**

*2) User-Partner:* Viewers demonstrated strong social awareness, maintaining synchronous locomotion patterns and social attention. Key behaviors included:

*a) Visual Perception:* Viewers looked towards partners 1.6 times per minute on average, crucial for maintaining social synchronization and leadership roles. This informed our second design goal:

> **Design Goal 2: Support remote users in perceiving the location and status of local users to improve social awareness.**

*b) Physical Contact:* Nine out of 16 pairs engaged in physical contact, conveying social intentions and facilitating role transitions. This led to our third design goal:

> **Design Goal 3: Enhance embodied interaction between local and remote users to improve social awareness.**

*3) User-(Partner-Environment):* Viewers exhibited strong situational awareness, forming joint references to environmental information. Gaze following (1.5 times/minute) and gesture indication (2.5 times/minute) were key behaviors. This informed our final design goal:

**Design Goal 4: Support joint referencing of environmental information by both local and remote users to improve situational awareness.**

## III. Implementation

We developed TeleAware Robot, a telepresence robot supporting collaborative locomotion, based on our design goals. The implementation comprises hardware and software components.

The robot body includes: (1) Two DC brushless geared motors with controllers (2) ROS main control board STM32F407VET6 (3) Customized polyurethane rubber wheels (4) UGREEN 1200W mobile power supply (5) HIKVISION DS-UVC-U64 Pro 2K camera (6) TP-LINK 600W Binocular Surveillance Camera (7) Two force sensors (8) 27-inch REDMI display (9) Wireless projector (10) Two HTC Vive trackers (11) Laptop for software and control.

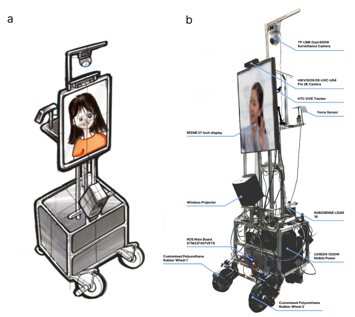


Fig. 2. TeleAware Robot. a) Schematic; b) Final implementation.

The remote user side includes: (1) HIKVISION E14a 2K camera (2) Aluminum desktop stand (3) iPad 7 (4) Laptop for software.

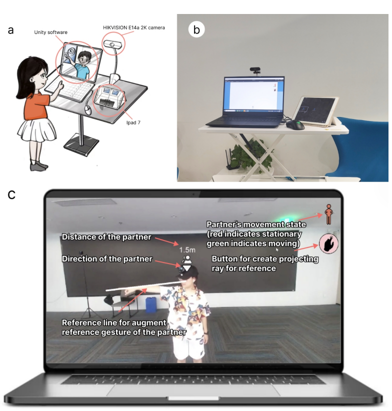


Fig. 3. Remote user environment. a) Schematic; b) Physical setup; c) Remote user interface.

We developed the software using Unity3D, incorporating: **Agora-RTM** for remote video calls **Agora-RTC** for remote messaging **OpenCV for Unity** for image recognition, including YOLOX Object Detection and MediaPipe Pose Estimation

## IV. Experimental Study

We conducted a 2 $\times$ 2 mixed experiment with two independent variables: robotic system [TeleAware Robot, Standard Telepresence Robot] and task role [Leader, Follower].

24 participants (M = 26.25, SD = 7.4, 10 males, 14 females) were recruited. Participants performed leader and follower roles in four experimental rounds, viewing display boards in a simulated exhibition hall. An 8 $\times$ 8-meter indoor area was used, equipped with tracking systems and cameras. Participants completed training and a 60-minute formal experiment, with counterbalanced task sequences. We collected log data, memory questionnaire data, video data, measurement scales, and conducted interviews.

### A. Findings

TeleAware group showed lower cognitive demands and frustration. We used Hart and Staveland's NASA-TLX scale to assess the overall workload and work experience of users under different robot conditions. The results showed that the TeleAware group perceived significantly lower cognitive demands (p=0.046, t=2.017) and less frustration and negative emotions (p=0.040, t=2.076) compared to the standard condition.

TeleAware condition resulted in higher social connection scores and closer physical proximity. TeleAware users reported enhanced mutual awareness and social presence. The average distance in the TeleAware group was 1.21 meters, compared to 1.48 meters in the standard condition group. The significantly smaller average distance in the TeleAware group (p=0.046, t=-2.849) indicates closer collaborative locomotion between the local and remote users under the TeleAware condition, as exemplified in Fig. 4.

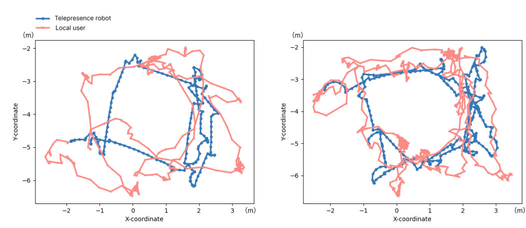


Fig. 4. Examples of the trajectories of the telepresence robot and the local user under two conditions. Compared to the standard condition, trajectories under the TeleAware condition exhibit higher overlap and closer average distance.

## V. Conclusions

We present TeleAware robot, a telepresence system for collaborative locomotion. Based on an observational study of colocated exhibition touring, we developed a User-Partner-Environment awareness framework and design goals. Our experiment with simulated guided visits showed TeleAware Robot reduced workload, improved social proximity, mutual awareness, and social presence. We discuss mobility impact, user roles, and propose design implications for future telepresence robots in remote collaborative locomotion.

## REFERENCES


[1] L. Alem and W. Huang, “Developing mobile remote collaboration systems for industrial use: some design challenges,” in *Human-Computer Interaction–INTERACT 2011: 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part IV 13*. Springer, 2011, pp. 442–445.

[2] J. Pejoska-Laajola, S. Reponen, M. Virnes, and T. Leinonen, “Mobile augmented communication for remote collaboration in a physical work context,” *Australasian Journal of Educational Technology*, vol. 33, no. 6, 2017.

[3] Y. Wu, S. You, Z. Guo, X. Li, G. Zhou, and J. Gong, “Mr. brick: designing a remote mixed-reality educational game system for promoting children’s social & collaborative skills,” in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, 2023, pp. 1–18.

[4] C. Neustaedter, G. Venolia, J. Procyk, and D. Hawkins, “To beam or not to beam: A study of remote telepresence attendance at an academic conference,” in *Proceedings of the 19th acm conference on computer-supported cooperative work & social computing*, 2016, pp. 418–431.

[5] L. Yang, B. Jones, C. Neustaedter, and S. Singhal, “Shopping over distance through a telepresence robot,” *Proceedings of the ACM on Human-Computer Interaction*, vol. 2, no. CSCW, pp. 1–18, 2018.

[6] J. Rasch, V. D. Rusakov, M. Schmitz, and F. Müller, “Going, going, gone: Exploring intention communication for multi-user locomotion in virtual reality,” in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, 2023, pp. 1–13.

[7] J. Young, T. Langlotz, S. Mills, and H. Regenbrecht, “Mobileportation: Nomadic telepresence for mobile devices,” *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 4, no. 2, pp. 1–16, 2020.

[8] E. Dim and T. Kuflik, “Automatic detection of social behavior of museum visitor pairs,” *ACM Transactions on Interactive Intelligent Systems (TiiS)*, vol. 4, no. 4, pp. 1–30, 2014.