360 Robot Hand System for Omni-directional Interaction by Multiple Users

Yoshiki Watanabe
Nozomi Hayashida
yoshiki@ucl.nuee.nagoya-u.ac.jp
linda@ucl.nuee.nagoya-u.ac.jp
Nagoya University
Naogya, Aichi, Japan

Shin Katayama
Kenta Urano
shinsan@ucl.nuee.nagoya-u.ac.jp
vrano@ucl.nuee.nagoya-u.ac.jp
Nagoya University
Naogya, Aichi, Japan

Takuro Yonezawa
Nobuo Kawaguchi
takuro@nagoya-u.jp
kawaguti@nagoya-u.jp
Nagoya University
Naogya, Aichi, Japan

ABSTRACT

The rise of diverse digital environments like digital twins and the metaverse emphasizes the importance of telepresence methods for linking users across different spaces. These methods aim to boost communication and services between these spaces. This paper introduces RHS360, a 360-degree robot hand system designed for inter-spatial communication. RHS360 ensures the robot hand aligns precisely with the user in cyberspace, adjusting based on the user's movements in the virtual realm. This enables the robot hand not only to aid communication and gestures but also to convey crucial social cues, enhancing the overall communication experience. Additionally, a user survey was conducted, revealing that observing the robot hand's movements significantly improved understanding their partner's thoughts and fostered a greater sense of intimacy. These findings suggest that the proposed method enhances communication between different spaces.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**.

KEYWORDS

Group Telepresence, Robot Hand System, Virtual Reality

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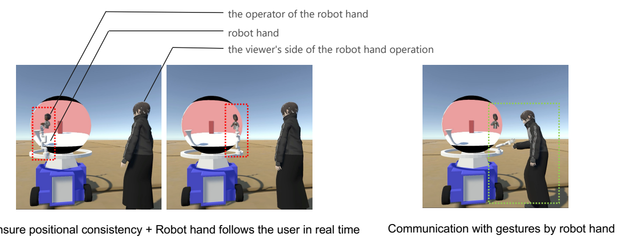

Figure 1: Functions provided by RHS360

1 INTRODUCTION

The increase in spatial diversity, like digital twins and the metaverse, highlights the importance of telepresence techniques for improving communication and services in these spatial domains. Stephen et al. introduced a method for groups in distributed spaces to gather in cyberspace[1]. We proposed MetaPo as a unified approach to connect distributed spaces[19]. In telepresence, the common approach involves high-definition, life-sized video calls showing a partner's appearance and behavior. However, high-definition video has limitations. Despite good quality, there's a concern that conversing through a display may create emotional detachment among partners[15]. As a potential solution, a hybrid approach combining telerobotics and video calling has been suggested.

Gestures make up over 60% of human communication meaning[9]. Instructing a robot hand to mimic these gestures has proven to speed up user response times, aid memory retrieval, improve collaborative task performance, and boost overall familiarity[11][17][14][4]. Robot hands are crucial for enhancing communication. Telepresence techniques, allowing remote control of robot hands through telerobotics, have the potential to significantly improve communication quality. However, when users are connected in a space with mobility, they can communicate in all directions, creating challenges. The alignment between the user on the display and the robot hand is not sustained, adversely affecting social cohesion among users and degrading the communication experience[15]. Addressing this issue is crucial.

In general, communication relies heavily on social cues, encompassing nonverbal signals that aid our understanding of others' actions and emotions in social contexts. Traditional text-based and online communication mediums, like voice calls and video conferencing, often overlook these crucial social cues, adversely affecting communication and the sender's social perception[5]. In the realm of telepresence technologies, like MetaPo, effectively conveying intended communication to specific users in a shared virtual space poses a challenge. Therefore, emphasizing the presentation of social cues becomes crucial. Despite the abundance of social cues in cyberspace, there is a lack of research addressing their effective presentation.

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Based on the provided context, the RHS360 system (see Figure1), when incorporated into our previous MetaPo framework[19], enhances the user experience through three key functions.

- Allows users in cyberspace to control a robot hand and communicate with others in different spaces through gestures
- Maintain positional consistency between the operator's position and the robot hand throughout communication
- Aligns the position of the robotic hand with that of the operator in real-time

In this study, we implemented RHS360 in a simulator and conducted a user study. The results clearly show that our approach improves understanding and fosters intimacy with communication partners.

2 RELATED WORKS

2.1 Gesture Communication with Robot Hands

Previous studies show that human-robot interaction has positive effects.Li et al. found that the physical presence of robots strongly influences human interaction compared to computer graphics-based agents[6]. Additionally, extensive research has examined the role of gestures in human communication. Dargue et al. systematically classified gestures into four types—iconic, metaphonic, deictic, and beat gestures—highlighting the advantages associated with each category[2]. Saunderson et al. explored how robots effectively convey emotions through gestures[13]. Tanaka et al. investigated positional inconsistency[15], finding no difference in spatial sharing and social cohesion with size incongruence but improvement with positional consistency.

As discussed earlier, using robots to convey gestures in telepresence has been effective. However, a drawback is that the robot hand usually stays still and doesn't adjust to the 'user's movement within a space,' which is common in telepresence scenarios like MetaPo.

In our proposed method, RHS360, the robot hand can move in a 360-degree direction while the user in cyberspace operates it for communication. This ensures that the robot hand aligns with the user's position, allowing effective gesture communication. Our study focuses on achieving this positional consistency.

2.2 Presentation of social cues

Social cues are vital in communication. Cyberspace is considered to have a stronger social presence than other technology-mediated communication forms, offering visual, auditory, tactile, and olfactory cues[10][18]. Understanding how technological features influence social presence perception is crucial for designing virtual platforms. Current research on representing social cues is advancing.

Daniel et al. introduced a new method to enhance social behavior in cyberspace by incorporating three key social cues: eye contact, joint attention, and grouping. The results show significant potential for these cues to influence social perception and behavior in virtual environments. They increase the sense of social presence in multi-user settings, impacting participants' behavior, such as increased eye contact and focus on avatars and objects within the virtual scene[12]. Jann et al. represented a social cue, Gaze Cue, using a 3D cone to show the user's field of view, highlighting the object they are looking at, and providing a direct video mirror of the user's viewport[3].

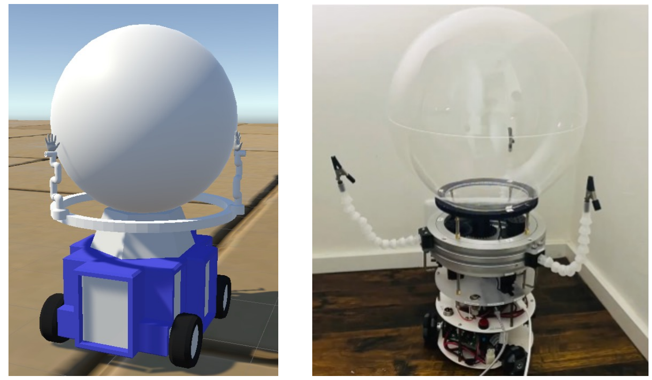

Figure 2: RHS360 prototype (left: cyber space, right: physical space)

Research has explored social cues in cyberspace, but the challenge is the lack of a comprehensive method for both "cyberspace and cyberspace" and "cyberspace and physical space."

The inclusion of RHS360 enables a consistent provision of social cues for communication in both cyberspace and between cyberspace and physical space. This enhances social presence and improves multi-user communication experiences across different spatial contexts.

3 RHS360 : ROBOTHAND SYSTEM 360

3.1 Design

RHS360 is compatible with both physical and cyber spaces in MetaPo (see Figure 2). It enhances communication by synchronizing the operator's position with the robot hand in real time, ensuring alignment. Social cues generated during this process contribute to the improvement. MetaPo, equipped with RHS360, uses the following devices.

- VR Device : Meta Quest2[1]
- 360-degree camera : RICOH THETA V[2]
- LED spherical display : SP2.5[3]
- Robot Hand : myCobot 280[4]
- autonomous mobile robot : HAKOBOT[5]

3.2 Inter-Space Communication

MetaPo introduces two key communication modes: the Mixed Link for remote communication using panoramic audiovisual media, and the Immersive Link for heightened immersion through VR. The Mixed Link allows users in different locations to interact while staying in their respective spaces. In the Immersive Link, remote

[1]https://www.meta.com/jp/quest/products/quest-2/
[2]https://theta360.com/ja/about/theta/v.html
[3]https://www.hscled.com/product/sphere-led-display.html
[4]https://www.elephantrobotics.com/myCobot/
[5]https://hakobot.com/

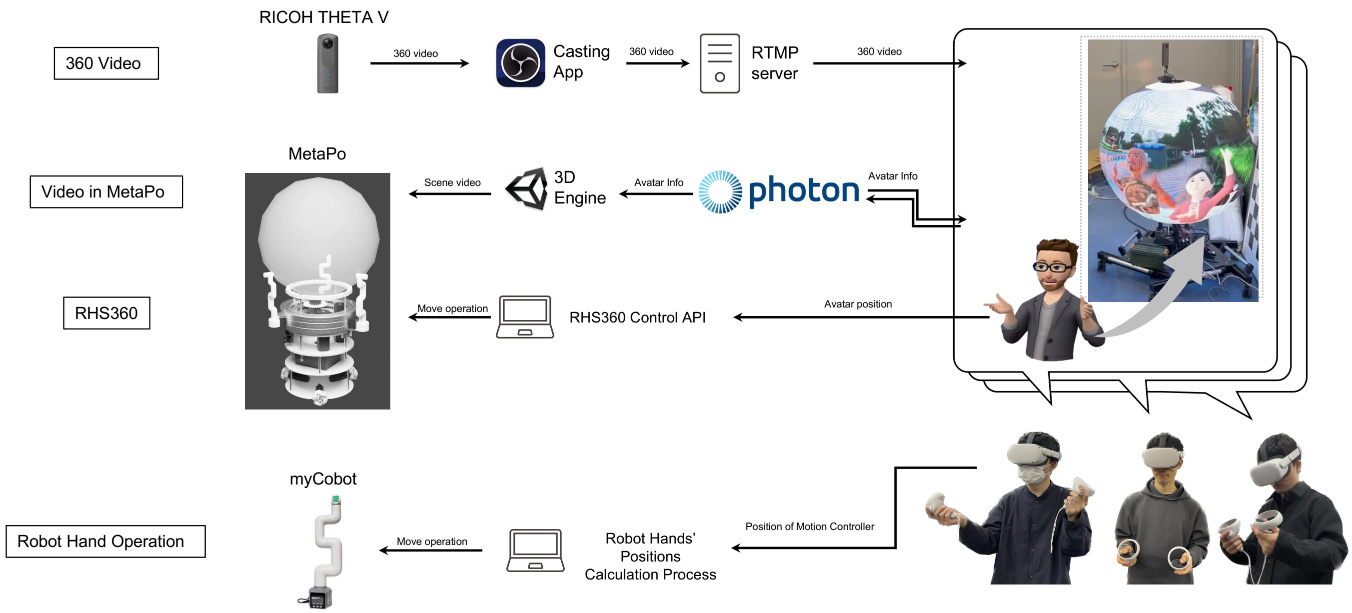

Figure 3: system configuration

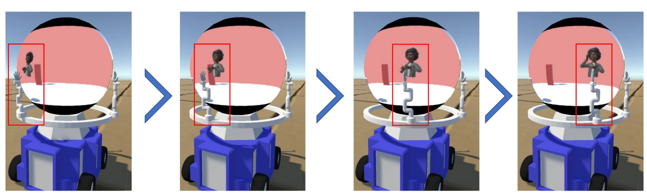

Figure 4: Social cue provided by the system

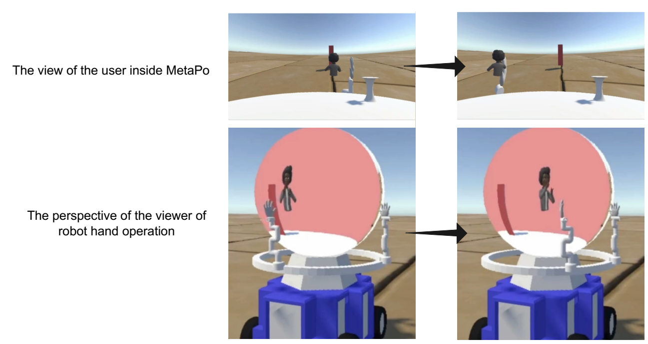

Figure 5: MetaPo simulator with RHS360

users wear VR devices to enter MetaPo's virtual portal, experiencing immersive communication with a 360-degree panoramic image. Additionally, users in cyberspace can control robot hands in the communicated space for gesture-based communication along with video and audio.

Figure 3 displays the system configuration of MetaPo with RHS360. In the RHS360 framework, when a cyberspace user switches to robot hand operation mode, the API automatically selects an available, unoccupied robot hand. This chosen hand aligns with the user's arm for consistent positioning. The ability to convey messages through gestures, ensuring precise alignment between the user and the robot hand, fosters social cohesion and significantly enhances communication. At the communication onset, the recipient observes the robot hand moving in sync with the cyberspace user, as in Figure 4. This synchronized movement serves as a crucial social cue, indicating the intended recipient of the robot hand operator's communication.

The proposed method efficiently addresses two main challenges in communication across spaces with freedom of movement, such as in MetaPo: maintaining precise position consistency and presenting social cues proficiently.

4 USER EXPERIMENT AND RESULTS

To assess RHS360's impact on telecommunications, we developed a simulator using the Unity framework[6] (see Figure 5).

4.1 User experiment

This study involved ten participants (9 males in their 20s, 1 female in her 50s) using a simulator to communicate through a robot hand in MetaPo. The goal was to test the hypothesis that "RHS360 enables more face-to-face-like communication than a fixed robot hand." In this user survey's initial phase, we focused on one-on-one communication rather than group interactions. Participants experienced two patterns during the survey: one with a fixed robot hand and the other with RHS360, as outlined in the two cases mentioned below (see Figure 6).

- Case 1: User experience for the operator of the robot hand

[6]https://unity.com/ja

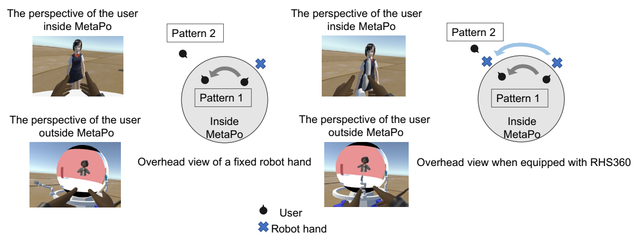

Figure 6: User Survey Flow

(1) Put on the VR device and move to the virtual portal in MetaPo
(2) Move to the front of the communication partner and make a handshake motion
(3) Watch the communication partner return the handshake

- Case 2: User experience on the side of observing robot hand operation

(1) Put on a VR device and move to cyberspace outside MetaPo
(2) Watch as the communication partner moves to the front of you and makes the motion of shaking hands
(3) return a handshake

After participants experienced both patterns, they filled out a questionnaire and underwent interviews. We used a portion of the H-MSC-Q, a Quality of Experience (QoE) measure in telepresence[16], along with our own questions, using a 5-point Likert scale for assessment. While there are various QoE evaluation indices for telepresence, like SocialVR-Q[7] and MPS[8], we chose the H-MSC-Q because it's less sensitive to secondary factors such as context, content, user state, and personality compared to other metrics. This reduced sensitivity is due to the inclusion of evaluation items in the H-MSC-Q that aren't dependent on such contextual and individual variables.

In addition to collecting gender and age information, the questionnaire consists of nine items (Q1 through Q9). Q1 to Q5 are adapted from the H-MSC-Q, and Q6 to Q9 are specifically designed for this study.

Q1 I felt the presence of the other person(s)
Q2 I felt an emotional and intellectual connection with the other person(s)
Q3 The appearance of the other person(s) felt normal
Q4 While communicating, my reasoning felt normal
Q5 While communicating, my behavior felt normal
Q6 The robot hand felt like my/their arm.
Q7 I felt like the other person was right in front of me
Q8 I felt a sense of intimacy with my partner
Q9 I felt as if I were holding the person's hand or being held by them

4.2 Results

Tables 1 to 2 present the survey results, and visual representations are in Figures 7 and 8. For Case 1 and Case 2, we used a Wilcoxon signed-rank sum test to compare fixed robot hand and RHS360-mounted cases, with a significance level set at $p < 0.05$. No significant differences were observed for any items in Case 1.

Table 1: The result of Pattern 1

Question \ Score	With a fixed robot hand 5	4	3	2	1	With RHS360 5	4	3	2	1
Q1	4	5	1	0	0	1	4	3	1	1
Q2	5	1	2	2	0	0	1	3	4	2
Q3	2	5	1	2	0	1	3	1	4	1
Q4	2	4	3	1	0	0	4	3	3	0
Q5	3	4	2	1	0	2	4	1	2	1
Q6	1	2	2	3	2	1	1	4	2	2
Q7	4	4	0	2	0	1	2	2	4	1
Q8	3	3	2	1	1	0	0	5	5	0
Q9	1	3	1	5	0	0	1	1	1	7

(Strongly agree: 5, Agree: 4, Neither agree nor disagree: 2, Disagree: 2, Strongly disagree: 1)

Table 2: The Result of Pattern 2

Question \ Score	With a fixed robot hand 5	4	3	2	1	With RHS360 5	4	3	2	1
Q1	6	2	1	1	0	2	4	2	2	0
Q2	1	5	2	1	1	0	4	5	0	1
Q3	4	2	1	3	0	2	4	2	2	0
Q4	2	4	3	1	0	2	5	2	1	0
Q5	0	5	4	0	1	4	5	1	0	0
Q6	0	6	0	4	0	5	5	0	0	0
Q7	5	2	3	0	0	4	2	2	2	0
Q8	3	2	3	2	0	2	3	2	3	0
Q9	0	3	0	6	1	1	1	3	4	1

(Strongly agree: 5, Agree: 4, Neither agree nor disagree: 2, Disagree: 2, Strongly disagree: 1)

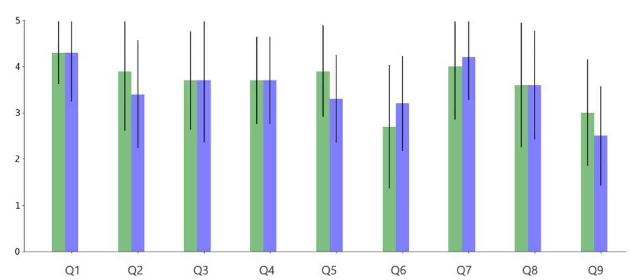

Figure 7: Results of Pattern 1 (Graph of mean values, error bars are standard deviations)
(Green: Fixed robot hand, Blue: RHS360 equipped)

However, in Case 2, Q4, Q6, Q7, Q8, and Q9 showed statistically significant results below the threshold, indicating consistently higher mean values with the proposed method in each of these items.

5 DISCUSSION

5.1 User experience for the operator of the robot hand

As depicted in Figure 7, user experience in MetaPo showed no notable differences with or without RHS360. Various interpretations are possible in this context.

In our simulator, we used animation, not physical manipulation, for experiments. This made users feel less in control of the robot hand. Simultaneously displaying both the avatar's and robot hand in the field of view caused discomfort and negatively affected the communication experience. In post-experiment interviews, some

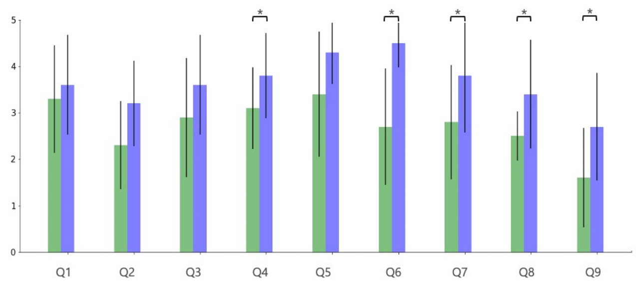

Figure 8: Results of Pattern 2(Graph of mean values, error bars are standard deviations)
(Green: Fixed robot hand, Blue: RHS360 equipped)

participants felt uneasy, mentioning "Seeing two hands felt awkward" and "desiring real-time movement of the robot hand". On the flip side, positive feedback included "Feeling like I'm operating the robot hand when visible is beneficial" and "Having the robot hand in front felt like my own hand." This suggests that improving the usability of the robot hand could enhance the communication experience.

5.2 User experience on the viewer's side of the robot hand operation

Figure 8 shows significant differences in user experience outside MetaPo, specifically in Q4, Q6, Q7, Q8, and Q9. Additionally, RHS360 usage resulted in a higher mean value. Q4 assesses whether the H-MSC-Q criterion "evokes thinking similar to everyday life." RHS360 is presumed to improve the detection of the partner's desire for a handshake. This improvement is attributed to clear social cues provided by real-time tracking of the robot hand during interaction. In post-experience interviews, participants expressed observations such as, "I wondered if the robot hand was looking at me when it didn't follow the partner," and comments like, "It's clearer when the system is coming towards me." Additionally, sentiments were shared, such as, "There was a sense that the partner's awareness was directed towards me, and I felt a desire to shake hands." Q6 to Q9 evaluate naturalness of system operation, space sharing, intimacy, and psychological distance. Significant differences were found in all items, with users using RHS360 showing higher mean values. This suggests the system works well for users outside of MetaPo, improving communication by reducing psychological distance and increasing intimacy. User comments, such as "I felt disconnected without the system," "The robot hand approaching made me feel closer," and "The system's presence gave me a sense of intimacy," support this positive effect.

6 CONCLUSION

This paper presents a telepresence communication method using RHS360 to connect spaces like MetaPo. A simulator-based user survey confirmed that users outside MetaPo "think as they do in their daily lives" and "experience a reduction in psychological distance." These results indicate that RHS360 enhances communication across different spaces. In the future, we plan to enhance user experience within MetaPo and conduct user surveys not only in cyberspace but also in physical spaces. Additionally, we will explore user interactions in scenarios involving multiple individuals.

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