ChaMEleon: Identity-Adjustable Remote Collaboration System in Virtual Reality

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Abstract

Recent advancements in virtual reality (VR) technology have revolutionized remote collaboration; however, existing platforms often constrain users' natural identity expression through limited avatar customization and fixed voice options. We propose ChaMEleon, a novel VR-based system that enables dynamic identity adjustment through customizable avatars and voice modulation across various collaborative contexts. The system allows users to modify their visual and auditory representations according to specific interaction scenarios such as problem-solving, brainstorming, and networking. Through experiments with 12 participants across different collaborative tasks, results demonstrated that the anonymous identity improved problem-solving efficiency and reduced user fatigue, while realistic identities enhanced engagement and satisfaction levels. This research contributes to the field by providing empirically validated design guidelines for context-appropriate identity selection in VR-based remote collaboration, ultimately promoting more effective and inclusive virtual interactions.

Keyword

Virtual Reality, Remote Collaboration

1. Introduction

The advent of COVID-19 triggered unprecedented growth in the adoption of remote collaboration tools like Zoom, Spatial, Gathertown. These platforms emerged as critical facilitators of social interaction, enabling meaningful connection even during mandated physical separation user appearance in remote collaboration platforms fundamentally affects interaction quality across contexts. Research demonstrates that optimized identity presentation enhances social presence and performance, while design limitations or customization restrictions hinder effective interaction. Studies of video conferencing reveal specific challenges: women report stress from continuous appearance visibility, while ethnic minority men cite pressure to maintain elevated presentation standards for credibility.

In remote collaboration, user identity refers to the visual and auditory appearance through which users wish to be perceived by other participants in the collaboration. This research leverages the advantages of eXtended Reality (XR) environment to enhance the degrees of freedom in identity adjustment during remote collaboration, thereby providing context-specific user identities and facilitating both quantitatively and qualitatively positive interactions.

Contemporary XR collaboration platforms predominantly offer avatar and voice expression personalization methods. However, these methods are evaluated as diminishing the quality of identity expression, primarily due to providing options derived from biased assumptions about users. For instance, users report discomfort with pre-fabricated avatars of limited quantity that potentially reinforce racial stereotypes. Furthermore, situations arise where avatar creation defaults to male gender settings or lacks options beyond binary gender choices, thereby provoking identity confusion through gender bias and objectification. The expansion of social interaction contexts through XR adoption has led to a diversification of required norms corresponding to individual identities and characteristics. Consequently, the imposition of standardized avatar and voice expression modalities may impede interaction and task performance across diverse social contexts.

We propose ChaMEleon, a Virtual Reality (VR)-based remote collaboration system that provides and recommends avatar and voice expression modes appropriate for different social interaction contexts. The system facilitates productive interaction by positively influencing users' context-dependent self-perception within remote collaborative environments. We conducted user experiments across various social interaction contexts (problem-solving, brainstorming, and networking) to empirically examine the impact of identity adjustments on social interactions. Ultimately, through these empirical validations, we aim to provide design guidelines for selecting appropriate identities tailored to specific social interaction contexts.

The key contributions of this research include:

- We propose a VR-based remote collaboration system enabling adjustment of avatar and voice expressions.
- We validated the impact of identity adjustments on by experimenting with the proposed system in various social interaction contexts.

2. Related Work

2.1 Identity Adjustment in Remote Collaboration

Identity expression in remote collaboration is fundamental to collaborative success and user experience quality. Collaborators express their identity through visual and auditory elements, directly affecting collaboration effectiveness. However, current technological constraints limit users' ability to freely adjust their identities, potentially affecting participation levels and communication efficiency.

Visual identity technology has primarily been implemented through avatars. While research has validated the impact of avatar realism on social presence and avatar appearance on self-affirmation and participation, limitations in visual representation may influence users' contextual adaptation. In the auditory identity domain, real-time voice modulation technology has enabled situation-specific voice characteristic adjustments. Studies have explored digital voice transformation and modulation patterns, with VR platforms implementing voice pitch adjustment features. Despite these technological advances, constraints in adjustment range and integration may influence natural identity expression.

2.2 Remote Collaboration in Social Interaction Contexts

The significance of identity adjustment has been demonstrated across various social contexts. Context-appropriate identity expression emerges as a key factor in enhancing collaboration quality and effectiveness. Studies have shown that realistic avatars improve engagement in business meetings, educational environments demonstrate enhanced learning outcomes, and VR dance environments show increased confidence. Research on spatial scale's influence on small group discussions and networking further emphasizes the necessity of context-specific identity adjustment.

However, current research presents two critical limitations. First, the segregated study of visual and auditory identities has left a gap in understanding their integrated impact. Second, research focusing on single interaction types and limited participants (n<3) may not fully capture the complexity of real collaborative environments. This restricted approach may limit our understanding of identity adjustment effects in environments where problem-solving, brainstorming, and networking coexist.

This study addresses these limitations by developing an integrated identity adjustment system and empirically validating its effectiveness across diverse social interaction contexts. Our aim is to comprehensively understand how context-adaptive identity adjustment influences collaboration quality.

3. ChaMEleon

The primary objective of this research is to propose a VR remote collaboration platform that provides and recommends appropriate levels of anonymity through integrated avatar and voice expression modes based on different social interaction contexts. We implemented our VR-based remote collaboration system using Unity engine as the primary development platform, leveraging its comprehensive XR interaction toolkit and rendering capabilities. The system architecture integrates the Meta SDK for VR interface development and the Photon Engine's PUN2 framework for real-time networking capabilities. This technical infrastructure enables robust multi-user functionality through a client-server architecture, supporting key features such as synchronized avatar movements, spatial voice communication with positional audio, and shared interaction spaces. The networking layer, implemented using Photon's reliable UDP protocol, ensures low-latency data transmission (average < 100ms) and consistent state synchronization across multiple users while maintaining scalability for up to 20 simultaneous participants in a single virtual space.
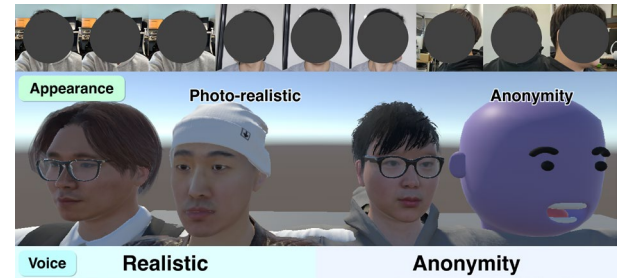
Figure 1. The identity adjustment system enables photo-realistic avatars from three photos (two profiles, one front) and voice modification to natural or anonymized forms.
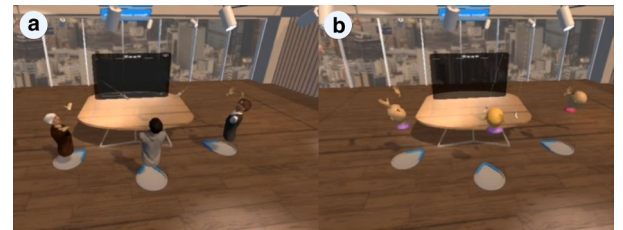
Figure 2. Users can collaborate using (1) a realistic identity or (2) an anonymous identity. Users collaborate from their individual stations and review shared materials on a central screen.

3.1 Identity Adjustment System

The system implements two distinct types of avatar representation to explore the impact of visual identity in virtual collaboration. Photo-realistic avatars are generated through an AI-powered avatar

creation system from Avaturn, which produces highly detailed 3D avatars from three user photographs (front, left, and right profiles) as shown in Fig. 1. These avatars maintain high visual fidelity to the user's actual appearance, including accurate facial features, expressions, and proportions. This approach ensures a professional representation while maintaining the user's authentic visual identity in formal collaboration contexts. Anonymous avatars are designed with minimal identifying characteristics, providing a simplified human form while maximizing privacy. The design prioritizes basic interactive capabilities, such as gesture recognition and movement tracking, while intentionally obscuring individual identifying features. This option enables users to participate fully in collaborative activities while maintaining anonymity when desired. The deliberate contrast between these two avatar types (see Fig. 2) enables us to systematically analyze how varying levels of visual representation impact user experience, social presence, and collaboration effectiveness across different interaction contexts.

The voice interaction system offers two primary modes to complement avatar representation and enhance user control over their virtual identity. Realistic voice transmits the user's original voice without modification through a low-latency audio pipeline, preserving authentic vocal characteristics, including tone, pitch, and emotional nuances. Anonymous voice utilizes Voicemod's real-time voice modulation technology to transform users' voices while preserving natural speech patterns and intelligibility. While Voicemod provides various voice modification options, we specifically selected modulation parameters that ensure user anonymity by altering fundamental voice characteristics without compromising speech clarity. This carefully calibrated modification obscures identifying vocal features while maintaining natural conversational flow, with the technology implementing advanced audio processing algorithms to minimize latency (<50ms) and artifacts.

3.2 System Workflow

Upon entering the collaboration environment, users can customize their identity representation through an intuitive interface that manages both avatar and voice settings based on their specific social interaction context. This identity management system is designed to support seamless transitions between different collaboration modes while maintaining user agency and system reliability. The system provides several key capabilities. For contextual identity configuration, users can select and combine avatar and voice representations appropriate for their current collaboration scenario, while smart recommendations adapt based on group composition and interaction goals. Users can either accept system recommendations or customize their identity settings manually. Regarding real-time adaptation, the system enables dynamic switching between identity representations during active sessions, smooth transitions between different avatar and voice modes without disrupting ongoing interactions, and immediate visual and audio feedback for configuration changes.

This comprehensive implementation creates a flexible yet structured environment for studying user behavior and interaction patterns. It enables us to analyze multiple aspects of virtual collaboration, including individual psychological responses to different identity representations, group dynamics under varying levels of identity disclosure, and the relationship between context-aware identity recommendations and user satisfaction.

4. User Study

4.1 Participants and Apparatus

We conducted an experiment to observe the impact of identity adjustments on interactions across various social interaction contexts. As described in Table 2, we recruited Twelve participants (6 female, $\mu = 27.17, \sigma = 3.07$) through internal institutional promotion. As illustrated in the Fig. 3, each participant performed the study while seated in a separate space, using a Meta Quest Pro Head-mounted Display (HMD) and controllers. All sessions were recorded with the participant's agreement. The study lasted approximately 70 minutes, and each participant was compensated with 25,000 KRW. This study was conducted with approval from the institutional review board.

4.2 Study Design

To investigate the effects of identity adjustments on multi-participant social interactions, participants were organized into four groups, with three participants assigned to each group. Groups 1 and 2 adopted anonymous identities, while Groups 3 and 4 adopted realistic identities to examine between-subject effects. Each group completed three types of interaction sessions: problem-solving, brainstorming, and networking. Each session lasted 15 minutes, followed by a 5-minute break and a survey to alleviate fatigue caused by the HMD. The problem-solving task aimed to assess the effect on collaboration performance using the desert survival task. Participants first worked individually to solve the problem for 7 minutes and 30 seconds, then discussed with their group members for the same duration to produce a final solution, following the standard study protocol. The brainstorming session evaluated the quantity and quality of ideas. Participants discussed two topics for 7 minutes and 30 seconds each: "The number of visitors to the campus library has decreased. Propose solutions to

increase visitors." and "Suggest ideas for a new club to promote diversity on campus.". The networking session examined the impact on perceived closeness. Two tasks were performed: a consensus-building task ("Select a travel destination none of you have visited before and create a travel plan.") and a keyword-photo-based task ("Based on the image below, discuss three keywords: festival, music, and summer.") Each task lasted 7 minutes and 30 seconds.

At the end of each session, participants completed a survey (as written in Table 1) measuring the effects of identity adjustments on both individual and collaborative experiences using a 7-point Likert scale. A partially balanced Latin square design was employed to control for order effects in session progression. Following the completion of the entire study, a brief group-based semi-structured interview was conducted to explore participants' overall experiences of interaction under identity adjustments.

Table 1. Evaluation Questions for User Study

Questions for User Study
Q1. Rate your engagement level during the interaction process.
Q2. Assess your satisfaction with the communication during the interaction
Q3. Indicate the fatigue level you experienced during communication (excluding HMD-related fatigue; A lower score indicates a higher level of fatigue).
Q4. Describe your sense of coordination during the communication process.
Q5. Express your feelings of connectedness during the communication process.
Q6. Measure the sense of presence you experience during the communication process.

4.3 Result 1: Task Performance

In the problem-solving session, participants with anonymous identities failed to solve an average of 5 problems within the given time limit, while those with realistic identities failed to solve an average of 8.5 problems. This result indicates higher task efficiency under anonymous identities. Regarding scores, participants in the anonymous identity group scored an average of 41.17 points ($\sigma = 3.52$) during individual problem-solving and 40 points during group problem-solving, showing a difference of 1.17 points. In contrast, participants in the realistic identity group scored an average of 32.33 points ($\sigma = 3.76$) individually and 31.5 points in group problem-solving, with a smaller difference of 0.83 points. These results further suggest better performance under anonymous identities. Qualitative evaluations (Fig. 4) revealed that anonymous identities showed better results in fatigue and presence, whereas realistic identities performed better in engagement, satisfaction, coordination, and connectedness.

However, no statistically significant differences were observed between the groups. In the brainstorming session, an average of 6.5 ideas were generated in the anonymous identity condition, compared to 6 ideas in the realistic identity condition. Additionally, idea quality, evaluated on a 7-point scale for creativity, averaged 4.67 in the anonymous identity condition and 4.81 in the natural identity condition. Anonymous identities demonstrated better outcomes in fatigue and connectedness, while realistic identities performed better in engagement, satisfaction, and coordination. Again, no statistically significant differences were found between the groups. For the networking session, anonymous identities showed better results in satisfaction, fatigue, connectedness, and presence, while realistic identities performed better in engagement and coordination. However, no significant differences were observed. Notably, in terms of closeness—a key measure of the networking session—anonymous identities yielded better results.

4.4 Result 2: Speech Frequency and Duration

We investigated the effects of identity adjustment on speech frequency and average speech duration across different interaction scenarios. To examine group differences in speech frequency and average duration, we conducted t-tests for normally distributed data and Mann-Whitney U tests (MWU) for non-normal data. In the problem-solving session, the anonymous identity condition tended to elicit more frequent speech compared to the natural identity condition, with lower average speech duration; however, these differences were not statistically significant. In the brainstorming session, the anonymous identity condition resulted in significantly higher speech frequency (MWU, $p < 0.01$), while a tendency for lower average speech duration was observed but not statistically significant. In the networking session, the anonymous identity condition was found to significantly increase speech frequency (t-test, $p < 0.01$) and reduce average speech duration (t-test, $p < 0.01$) compared to the natural identity condition. When analyzing the entire dataset, the anonymous identity condition was statistically validated to elicit more frequent speech (MWU, $p < 0.001$) but lower average speech duration (MWU, $p < 0.01$) than the realistic identity condition.

4.5 Subjective evaluation

Through post-interviews, we explored the impact of identity adjustments and remote collaboration environments on various social interaction scenarios. Participants using anonymous identities generally mentioned the sense of freedom and ease in expressing their opinions. For example, P1 stated, *"Having anonymity made it easier to speak. It might have been uncomfortable in an initial meeting, but I liked being able to share my thoughts on the topic without hesitation."* Similarly, P5 noted, *"Because it*

was anonymous, I could talk about my information freely without hesitation." Interestingly, in Group 2, participants exhibited openness during task discussions, yet showed shyness when transitioning to face-to-face interactions. Conversely, some participants highlighted challenges with anonymous identities. P2 shared, *"For brainstorming, constant communication is key from the start, but the lack of a sense of connection with the anonymized avatars caused some interruptions in conversation."*

For realistic identity, participants expressed comfort in using realistic avatars. P7 and P8 commented, *"If this task were done in reality, it might have been awkward since we're meeting for the first time. But speaking through substituted avatars in VR felt comfortable."* However, both P7 and P9 expressed curiosity about how their avatars appeared in VR. Additionally, compared to conventional collaboration tools, participants appreciated the enhanced sense of co-presence in VR, with remarks such as, *"I felt more like we were in the same space in VR."* (P7, P9).

5. Discussion

The findings of this study both align with and challenge previous research on the relationship between identity adjustment and collaboration. Some results lacked statistical significance, highlighting areas for further investigation. To enhance the reliability of our findings, we plan to conduct additional user studies, taking into account the effect sizes observed in this study. Building a robust and reliable dataset will be a key factor in establishing design guidelines for identity combinations tailored to different social interaction scenarios.

Participants also highlighted inherent system issues and potential improvements during the user study. They reported minor communication delays that slightly disrupted interactions and expressed discomfort with the lack of non-verbal cues, such as facial expressions, in the current avatar system. This limitation required additional communication to manage turn-taking. Future research will explore avatar representation techniques that incorporate user facial expressions to facilitate smoother interactions.

6. Conclusion

We proposed and validated ChaMEleon, a VR-based remote collaboration platform enabling identity adjustments, across various social interaction scenarios. The results demonstrated that identity adjustments influenced task performance differently depending on the interaction context. Specifically, anonymous identities generally led to higher speech frequency, while realistic identities resulted in longer average speech duration. Our key contribution lies in empirically validating a multi-user system across diverse social interactions. To enhance the reliability of these findings, we plan to conduct additional user studies and leverage the results to establish design guidelines for applying identity adjustments based on specific contexts. Ultimately, this study highlights that individuals tend to prefer different identity types depending on the nature of the social interaction, and these preferences significantly impact task performance. This underscores the necessity of designing features and guidelines to facilitate contextually appropriate identity adjustments in remote collaboration environments.
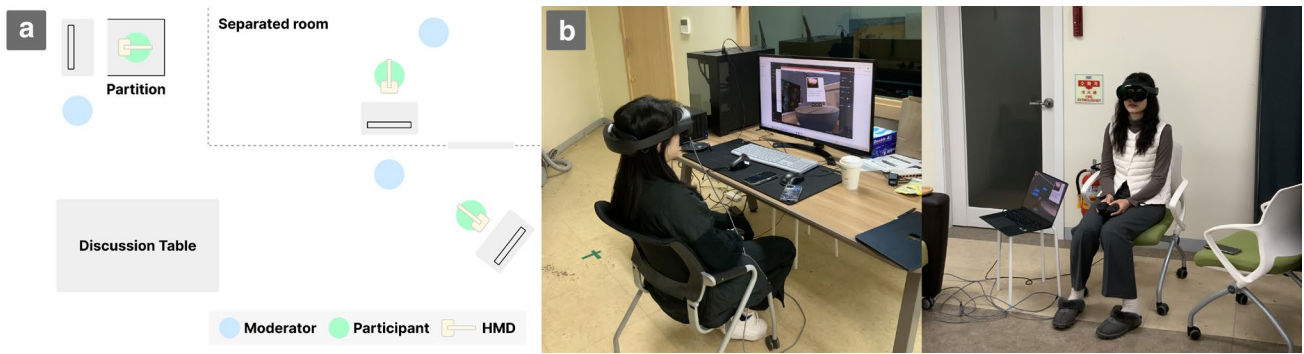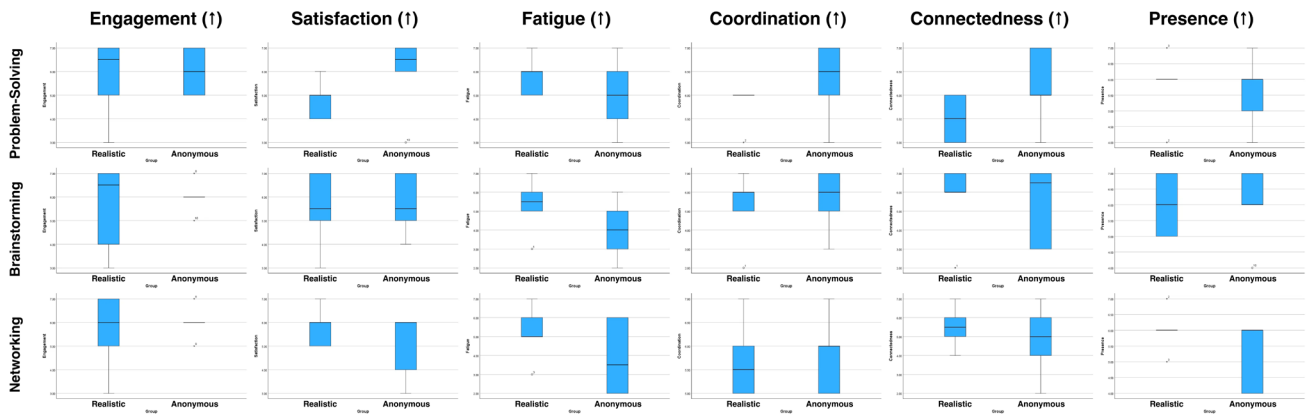
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Table 2. Demographic and Apparatus of Participants in the User Study

Participants	Gender	Age	Group	Identity	Task Order
P1	F	26			
P2	F	22	1	Anonymous	Problem-Solving, Brainstorming, Networking
P3	M	26			
P4	M	32			
P5	F	30	2	Anonymous	Problem-Solving, Networking, Brainstorming
P6	F	25			
P7	F	32			
P8	M	25	3	Realistic	Networking, Problem-Solving, Brainstorming
P9	F	29			
P10	M	28			
P11	M	26	4	Realistic	Networking, Brainstorming, Problem-Solving
P12	M	25			

Figure 3. (a) User study setup and (b) experiment footages. To reduce the voice interference among the participants in a shared space, they were placed in a separated room or a partitioned area during the study. The moderator was positioned near each participant to monitor any discomfort or the experimental situation.

Figure 4. Result of User Study