Effects of Avatar and Background Types on Users' Co-presence and Trust for Mixed Reality-Based Teleconference Systems

Dongsik Jo
ETRI/Korea University
dongsik@etri.re.kr

Ki-Hong Kim
ETRI
kimgh@etri.re.kr

Gerard Jounghyun Kim*
Korea University
gjkim@korea.ac.kr

Abstract

Recent advances in reconstruction and tracking technologies have allowed for easier live capture of humans as animated and realistic three-dimensional avatars. As such, traditional 2D video-based teleconference systems are evolving into immersive 3D-based ones, e.g., with teleported avatars situated in an interactive and shared augmented or virtual space. In such developments, one central concern, and a continued goal, is how to improve the teleconference experience and collaboration through the sense of co-presence and trust as felt by the participating users. In this study, we experimentally investigated the effects of the forms of the teleported 3D avatar (realistically reconstructed vs. character-like) and the environment background (realistic video vs. 3D VR) on the sense of co-presence and the level of trust. Our study shows that the participants generally exhibited a higher sense of co-presence when situated with a real environment background (realistic video) and greater confidence/trust when interacting with a reconstructed realistic looking avatar. These results can help the design of more effective collaborative teleconference and telepresence systems, according to their specific goals.

Keywords: Teleconference, virtual avatar, mixed reality, collaborative virtual environments, co-presence, trust.

*Corresponding author.

1. Introduction

Teleconference systems based on two-dimensional (2D) streamed videos have been used widely for business meetings and general communication among multiple parties [1][2]. Such video-based communication is particularly preferred in situations where face-to-face and thereby more convincing interaction and effective delivery of one's intention are important, not to mention the great savings in travel costs. However, the quality of the experience needs further improvement due to, e.g., the shortcomings of a fixed camera view, showing only the users' upper bodies, with inconsistent mutual gazes and limited room for movements [3][4][5].

In order to overcome these problems, many researchers have recently proposed the mixed reality (MR)-based teleconference systems in which remote participants are teleported as avatars into the counterpart user's environment to provide a more compelling communication experience with a higher sense of co-presence [6][7][8]. Note that co-presence refers to the sense of "being together with other people" in a remote physical or technology-generated environment (e.g., virtual/augmented/mixed reality [VR/AR/MR, respectively]) environment [9]. Moreover, such a system or environment with high co-presence is thought to empower participants to collaborate effectively through the enhanced level of persuasion and trust as perceived to be formed

in the same space [6]. In addition, the level of co-presence and trust will heavily depend on the type of representational forms, e.g. on the level of details of the teleported user, and the fidelities of the background of the environment [10][11].

For this reason, we investigated the effects of a 3D avatar and environment representation in immersive 3D teleconference systems on the sense of co-presence and on the level of trust. Specially, as envisioned in [10], our study focused on two major factors: (1) the form of the environment background (realistic video vs. 3D VR) and (2) the form of the teleported 3D avatar (realistically reconstructed vs. character-like).

The remainder of our paper is organized as follows. Section 2 first reviews the related works for our research. Section 3 provides the detailed experimental set-up and procedure for evaluating the co-presence and trust in the respective system configuration. Sections 4 reports on the main results and provides a discussion. Finally, Section 5 summarizes the paper and its main findings, and concludes with directions for future research.

2. Related Works

We outline three areas of work directly related to our work: (1) collaborative VR/AR/MR-based teleconference systems, (2) virtual avatars for teleconferences, and (3) participants' co-presence and trust evaluation of virtual avatars.

Collaborative VR/AR/MR-based teleconference systems: The "office of the future" was one of the earliest and pioneering works in terms of applying VR and MR to teleconferencing through the seamless spatial merging of two distant and remote environments [12]. Such a shared teleconference system has become much more feasible today with the continued advances in 3D sensing and capture technologies, immersive VR displays, and high-speed networks [13][14][15]. Just to introduce a few more recent notable results, Beck et al. developed a remote meeting system in which the participants were captured and represented as avatars in a shared virtual space using depth cameras and investigated various interaction scenarios [16]. Jo et al. investigated the use of life-sized teleported avatars for communication in the AR space [6]. Thalmann et al. introduced a remote collaborative system that assessed the co-presence between a human-like social robot and an autonomous virtual avatar [17].

Many researchers have been concerned about the type (and its effect) of VR/AR displays in terms of the level of communication and interaction through the perceived shared space between remote sites, namely, when using a life-sized transparent 3D display [13], an optical see-through head-worn display [6], an environment projection of the remote users [18], and an auto-stereoscopic 3D display [19]. More recently, as a future killer service model, a new active stereo depth camera technology (named Holoportation) that allows the precise 3D reconstructed models of people to be transmitted to a remote site in real time was introduced by Escolano et al. [20]. Similarly, Facebook showcased what the future social network service might look like in a virtual world using cartoon-like figures, which transports and connects participants in different places [21]. It remains to be seen how these new and different technologies should be combined and configured to derive the highest level of co-presence, trust, conveying of information, and collaboration.

Virtual avatars for teleconferences: Technologies for virtual life-sized and live 3D avatars that resemble an actual user in a photorealistic way have become quite mature lately [22]. For example, Shapiro et al. developed a rapid virtual human capture system that can generate a reconstructed 3D model mesh with texture blending using a depth camera [23]. Feng et al. introduced an auto-rigging method that creates the avatar's motion by using a scanned virtual character [24]. Moreover, researchers have been striving to transport, adapt, and retarget an AR character in a remote environment [6][25]. However, most previous works have focused on generating a virtual avatar and tracking its motion, and no comprehensive work has been done in terms of the effects of the different representational forms of an "AR" character.

Co-presence and trust evaluation of virtual avatars: There have been a few previous attempts to evaluate the aspects of emotional

response and co-presence when interacting with virtual avatars in immersive environments. Whereas most assessments were made through the use of surveys and questionnaires [18][26][27][28], physiological signals, such as the heart rate and skin conductance, have been suggested as alternative and indirect measures [29][30]. The various appearance and behavioral qualities of avatars have been controlled to study their effects, such as their shapes, gaze direction, animation qualities, and changes in the environment [31][32][33][34]. One emerging important criterion with respect to interaction in a teleconference application is the notion of "trust" [35]. Without trust, it would be difficult to apply a teleconference system to situations other than just the casual ones. Our work also investigated such issues with regard to the two main components of a teleconference scene configuration, namely, the forms of the avatars and the environment background.

3. Experiment

The experiment was divided into two parts for separately assessing (1) the sense of co-presence as felt with regard to a single counterpart avatar (Experiment 1) and (2) the trust as felt comparatively between two avatars that were different in their form and behavior. Both experiments were conducted in a teleconference-like situation.

3.1 Experiment 1: Co-presence

Experimental design: Experiment 1 was designed as a two-factor (two levels each) between-subject measurement (2 x 2). The first factor was the type of the avatar (realistically reconstructed vs. character-like) and the second one was the type of the environment background (realistic video vs. 3D virtual). We also included the baseline case of the conventional 2D video-based teleconference situation (2DV), resulting in a total of five different treatments, as shown in Table 1.

Figure 1 and Table 1 show the five test conditions including the (a) 2D video used as the baseline (2DV), (b) realistic avatar/realistic video background (R-AR), (c) character-like avatar/realistic video background (C-AR), (d) realistic avatar/3D virtual background (R-VR), and (e) character-like avatar/3D virtual background (C-VR).

Table 1: The five treatments of Experiment 1.

Test condition	Avatar type	Form of background
2DV (Baseline)	Conventional 2D video based	Conventional 2D video based
R-AR	Realistically reconstructed avatar	Real environment (video background)
C-AR	Character-like avatar	Real environment (video background)
R-VR	Realistically reconstructed avatar	3D Virtual environment
C-VR	Character-like avatar	3D Virtual environment

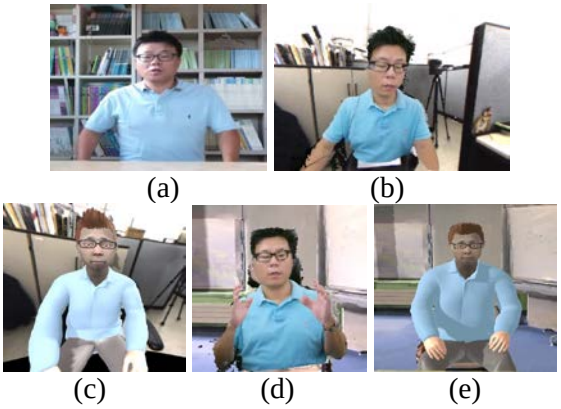


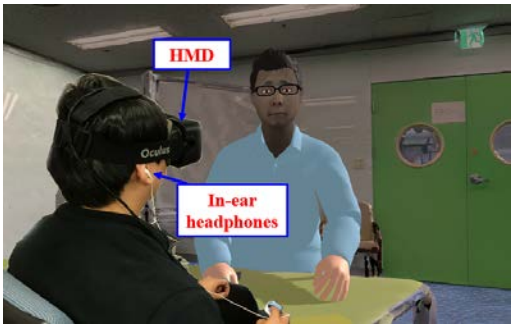
Figure 1: The five experimental test conditions according to two factors (forms of the avatar and background).

Experimental set-up: In all the test conditions, the subject wore a head-mounted display (HMD; Oculus Rift DK 2 [36]) to view the teleconference environment and interact with the avatar, even for a 2DV (i.e., a live video of the remote user/environment viewed shown in mono). For the remaining four test conditions, a stereoscopic 3D virtual environment was viewed (constructed using Unity3D [37]). In the case of C-AR and R-AR, the teleconference scene had a foreground 3D avatar with the rest represented as a live video of the subject environment captured from a dual camera attached to the HMD [38] (i.e., video see-through configuration). For the C-VR and R-VR, a graphic 3D environment was rendered.

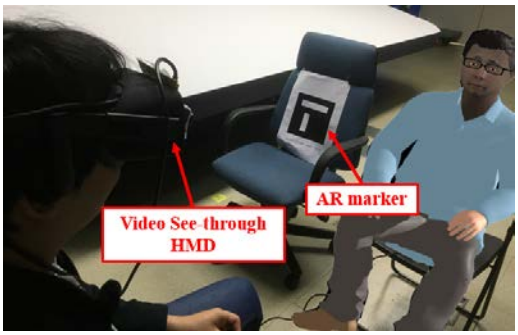
The life-sized character-like avatar was modeled off-line with resemblance to an actual person (with whom the subject was familiar) using tools such as the Blendshape [39] and Mixamo [40] for its facial expression appearance, animated motion, and lip-synching with prerecorded sounds. Likewise, the realistic looking character was "reconstructed"

into a 3D model off-line, whose raw point cloud data were captured by the Microsoft Kinect v2 sensor [41] and processed with the Brekel Pro PointCloud v2 for the mesh generation [42].

During the experiment, both types of avatars were "played" (on a personal computer running a 64-bit version of Windows 8) by the administrator (behind the curtain) according to the live response of the subject (e.g., what to answer and in which way to act). The AR avatars were registered (R-AR, C-AR) using fiducial markers placed in the subject environment. The respective set-ups are shown in Figure 2.



(a)



(b)

Figure 2: Experimental system set-ups: (a) VR mode (C-VR, R-VR) consisted of an HMD, an in-ear headphone, and a PC, and (b) AR mode (C-AR, R-AR) added with the dual webcams for the video see-through display and a fiducial AR marker for the registration of the avatar.

The user's sense of co-presence was measured with a survey based on [26][27][28]. We define co-presence as a measure of how much a subject perceives whether someone (or the avatar) is in the same room, as opposed to being just seeing on in a remote place or environment. The survey also included other questions about the perceived visual realism and naturalness (see Table 2).

Table 2: The three survey questions on co-presence, visual realism, and naturalness.

Category	Questions
Co-presence	Did you feel as if you were present with the interviewer in the same space?
Visual realism	Did the avatar look like a real person?
Naturalness	Did the avatar act naturally during the conversation/interview?

Experimental task and procedure: To assess the level of user-felt co-presence and its effect on person-to-person communication, we adopted the method originally proposed by Kwon et al. [43], in which a job interview situation was simulated, with the virtual avatar leading the conversation and taking the role of the interviewer. The avatar asked the subject a random sequence of 12 general job interview questions following the ones used in [43] (e.g., "What is your greatest weakness?"). Forty paid subjects (36 men and 4 women) with the mean age of 36.5 years participated in the experiment, who were divided into four groups to experience each test condition and provide the answers one by one. The avatar responded (e.g. speaking, making gestures and movements, etc.) according to the control of the administrator behind the curtain. The within-subject experiment was not used because of the unavoidable learning effect. Before carrying out the task for the given treatment, the subjects were first briefed about the overall purpose of the experiment and they experienced the 2DV condition to form an evaluation baseline. After the treatment, the subjects filled out the survey assessing the co-presence, visual realism, and naturalness in a seven-level Likert scale (see Table 2).

Hypotheses: On the basis of previous works [6][10][30] and our own research, we formed the following experimental hypotheses.

Hypothesis 1-1: We expect that AR (real video) background conditions (C-AR and R-AR) will exhibit a higher sense of co-presence compared than the VR background (C-VR and R-VR) and also 2DV. We posit that the realism of the background environment will strongly

influence the sense of co-presence and place where the subject and the avatar are situated in.

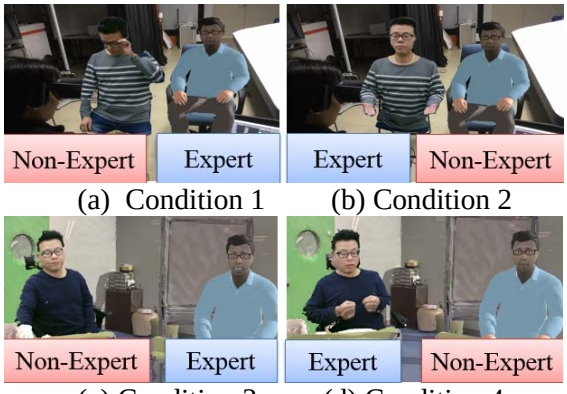
Hypothesis 1-2: Given the same background type, the character-like avatar condition will produce a higher level of co-presence than the realistic one. This hypothesis was based on previous findings pointing to the negative effects of the so-called uncanny valley [30]. We posit that the simplified (and perhaps clearer and even exaggerated) character representation in its facial expression and gestures would be more effective in eliciting higher co-presence based on the findings in [30][44].

3.2 Experiment 2: Trust

Experimental design: The evaluation of the avatar/background in terms of the subjects' trust was performed in another second experiment because it would require a simultaneous exposure to the competing avatar media types based on the work reported by [35][45] (whereas in Experiment 1, only one avatar appeared at a time in each treatment). Accordingly, we followed the same method (to evaluate the aspect of trust) as used by Pan and Steed [35], and compared to the two avatar forms, a realistic and a character-like, who were appeared at the same time in a given environment background. In addition, as was done so in [35], we used another experimental factor, namely, the behavioral characteristic (expertise of the avatar with the topic of the conversation), to further highlight the effects of the avatar form. For instance, a test of whether the avatar form affected trust toward the counterpart "over his/her actual expertise" would further clarify the effects of the avatar form.

Figure 3 shows examples of the four test conditions in Experiment 2: (a) a character-like expert and a realistic non-expert in an AR background environment (realistic live video), (b) a character-like non-expert and a realistic expert in an AR background environment (realistic live video), (c) a character-like expert and a realistic non-expert in a 3D VR environment, and (d) a character-like non-expert and a realistic expert in a 3D VR environment. In the experiment, the subjects tried to solve 20 general-knowledge questions (e.g., "Who among the following was a Dutch painter? Raffaello, Picasso, Rembrandt, or Gauguin"; see Table 3 for the other example questions). If necessary, the subjects could consult and receive an advice or a hint from one of the two avatars (one realistic and the other character-like). The level of expertise of the avatars was not known to the subjects initially. When consulted, the expert avatar would give correct answers and vice versa, which were progressively revealed to the subjects as the session went on to build trust toward one or the other [35][45]. The participants' advice-seeking behavior was recorded to investigate how their trust would be influenced by the avatar's expertise and its media form. In summary, the experiment was designed as a two-factor (two-avatar/expertise type pair × two environment background types) between-subject measurement (to again avoid any learning effects).

Experimental setup: The experimental setup in Experiment 2 was mostly the same as that in Experiment 1, except that two avatars (each with a particular visual form and expertise) appeared at the same time (for inducing trust associated with the differentiated behavior from the subject).



(a) Condition 1 (b) Condition 2

(c) Condition 3 (d) Condition 4

Figure 3: The four experimental test conditions for evaluating the level of trust in terms of the different avatar types and environment background.

Table 3: Three examples of the general-knowledge questions in Experiment 2.

Questions
Who among the following was a Dutch painter? (1) Raffaello, (2) Picasso, (3) Rembrandt, (4) Gauguin
Which sport does not use red cards? (1) Handball, (2) Fencing, (3) Field Hockey, (4) Basketball
Which country does not cross the Equator? (1) Equatorial Guinea, (2) Ecuador, (3) Brazil, (4) Congo

Experimental task and procedure: The experiment was carried out with 40 paid subjects divided into four groups of ten. Ten subjects attended each of the four treatments, as shown in Figure 3. The subjects were asked to answer the difficult general-knowledge questions (see Table 3) as correctly as possible and could also only choose one of two avatar advisers to ask for an advice. The subjects were free not to seek any help if they were already confident with their own answers. In the experiment, 20 multiple choice general-knowledge questions were given one at a time. During the experiment, we measured the advice-seeking rate and recorded which avatar was selected for help. After the experiment was over, the participants were asked to self-report on their level of trust toward the avatars in a seven-level Likert scale (e.g., "How much did you trust the reconstructed adviser's advice?").

Hypotheses: Previous research works have pointed to the phenomenon in which people generally trust the character-like avatar less than the realistic looking one because of its low-quality visual appearance and behavioral realism [35].

Hypothesis 2-1: Therefore, in contrast to Hypothesis 1-2 about co-presence, we expect that the character-like avatar to be less trusted despite the actual expertise (and vice versa).

Hypothesis 2-2: We also hypothesize that an AR (live video) background will increase the level of trust, regardless of the avatar form. We expect that a strong feeling of co-presence by the real AR background will have a positive effect on forming trust and lead one to asking for help [46].

4. Results and Discussions

4.1 Experiment 1: Co-presence

First, the statistical analysis revealed significant main effects with $p<0.05$ about the level of co-presence. One-way ANOVA analysis for the five experimental test conditions revealed a main effect of the factor (avatar and background combination) and the two-sample t-test between the 2DV baseline and the rest of the 3D environment conditions (i.e. C-AR, R-AR, C-VR and R-VR indicated a main effect as well. The level of co-presence of the 2DV baseline case was clearly lower than those of all the other test conditions, with a statistical significance (see Figure 4). This confirms that the 3D-ness and immersive nature of the AR or VR teleconference configurations brings about the feeling of togetherness much more effectively.

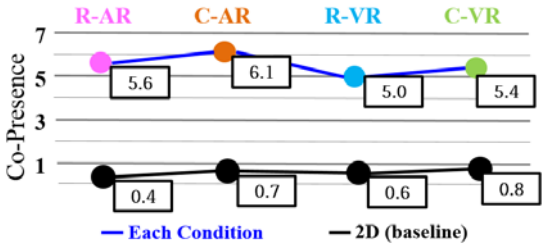


Figure 4: Level of co-presence among the five test conditions in Experiment 1.

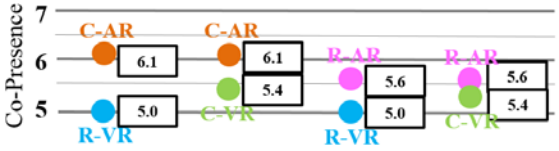
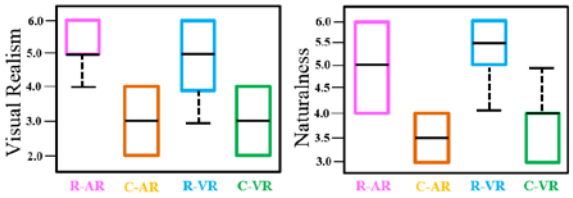


Figure 5: Effects of the environment background on co-presence. The AR (real video) background conditions (C-AR and R-AR) showed higher co-presence than the VR background conditions (C-VR and R-VR).

Moreover, Figure 5 shows the differences in the level of co-presence by the environment background factor. The two-sample t-test showed significant main effects between C-AR and R-VR ($t(17.41) = 4.71$, $p<0.05$), C-AR and C-VR ($t(17.84) = 2.88$, $p<0.05$), and R-AR and R-VR ($t(17.85) = 2.71$, $p<0.05$), respectively, indicating that the AR (real video) background generally brought about a higher level of co-presence. In particular, the latter two cases, namely, C-AR > C-VR and R-AR > R-VR, confirmed Hypothesis 1-1, indicating the significant influence of the environment background on user-felt co-presence.

In addition, a one-way analysis of variance on the other two survey questions confirmed that the realistically reconstructed avatar such as R-VR and R-AR exhibited a higher level of visual realism ($F(3,19.9)=17.45$, $p<0.05$) and naturalness ($F(3,19.5)=13.96$, $p<0.05$) over the character-like avatar such as C-VR and C-AR (see Figure 6). Nevertheless, the result with respect to co-presence showed that the

character-like avatar had higher scores than the realistically reconstructed avatar, supporting Hypothesis 1-2.



(a) (b)

Figure 6: Survey results on (a) visual realism and (b) naturalness.

4.2 Experiment 2: Trust

To assess the level of trust (or equally perceived reliability), we analyzed the advice-seeking rate/behavior (the number of advice-seeking and the type of avatar referred to by the subjects) among the tested conditions as originally proposed by Pan and Steed [35]. The correctness of the answers given by the subjects was not important.

The results showed that the realistically reconstructed avatar was felt to be more reliable and trustworthy than the character-like one. In Conditions 2 and 4 (with the realistic looking expert), the avatar was sought for an advice 154 and 150 times, respectively, out of the total 200 questioning sessions, and the subjects chose the realistic expert (90%). On the other hand, in Conditions 1 and 3, the avatar was sought only 131 and 130 times, whereas the expert character-like avatar was chosen 108 and 102 times (80%), respectively.

Figure 7 shows the trend over the four progressive stages in the 20 questioning sessions (S1 ~ S4 by five questions). At first, as the subjects did not know who the expert was, there was not a particular behavioral pattern as to whom to ask for help (in the Tukey honest significant difference test of means at the 95% family-wise confidence level, no significant effects were found, $p > 0.05$). However, in the second stage, the difference was quite clear. The Welch two-sample t-test pairwise comparison found that, in the questioning stages of S2-S4, there were main effects between Conditions 2/4 (realistic expert) and Conditions 1/3 (character-like expert) (two-sample t-test: S2: $t(38) = 7.75$, $p<0.05$; S3: $t(37.75) = 4.83$, $p<0.05$; S4: $t(37.98) = 3.98$, $p<0.05$, respectively). To summarize, Conditions 2 and 4 showed the effects of realism on the subjects' belief or choice of who the expert was, despite being quite clear who the expert "actually" was toward the end of the questioning session (e.g., despite getting a wrong answer from a non-expert avatar). In other words, participants showed differences in forming trust and seeking advices (i.e. more advice sought from the trustworthy avatar) according to the type of expert avatar.

The subjective and self-reported assessment of trust is in Figure 8 and it matches the advice-seeking behavior in a consistent manner. In Conditions 1 and 3, compared to Conditions 2 and 4, the realistic avatar was trusted more despite being clearly known to be a non-expert at the end of the questioning sessions. This validated Hypothesis 2-1.

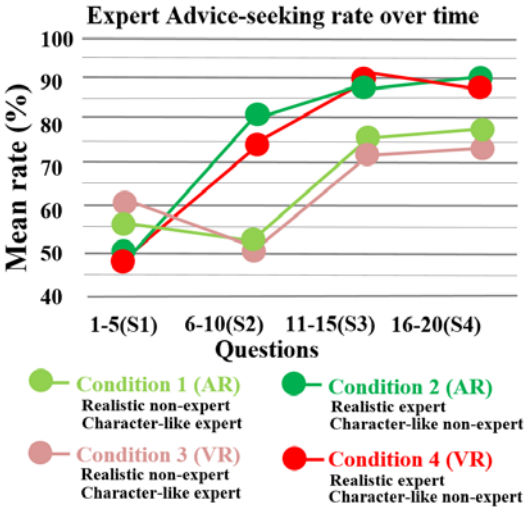


Figure 7: Changes in the percentage of the expert-seeking rate over time (divided into four progressive stages each by five questions).

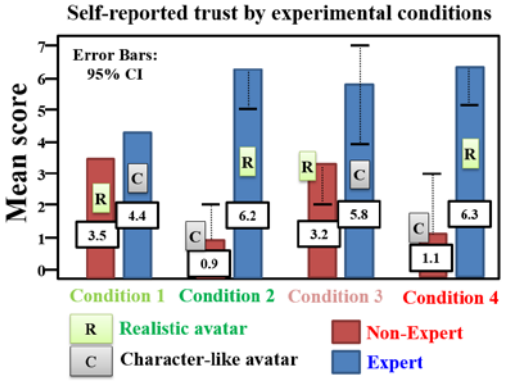


Figure 8: Self-reported trust in the four experimental conditions. Statistically significant differences were found for all the conditions, $p < 0.05$).

As for Hypothesis 2-2, we analyzed whether the AR (live video) background (already found to have effects toward co-presence) had any effect on the level of the subjects' trust. Figure 9 shows the interaction plot between the two experimental factors, and it indicates that the character-like avatar was highly reliable and trustworthy in the VR environment, but was significantly lower in the AR environment (background × avatar type, $p = 0.012 < 0.05$). Thus, we did not find the AR (real video) background to have any effect on the trust level, and, thus, it invalidates Hypothesis 2-2. On the other hand, some participants reported that the avatar's eye contact and facial expressions were more important than the type of background for eliciting a higher level of trust as reported in [47].

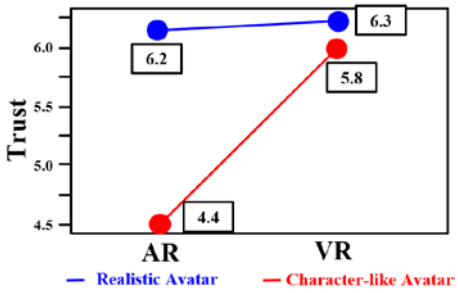


Figure 9: Interaction plot in terms of the self-reported trust between the type of background and the form of the avatar

4.3 Discussions

The experiment results can be summarized and explained as follows in terms of how future MR-based teleconference systems should be designed:

- Compared to 2DV, all 3D-based conditions with VR/AR background environments exhibited a relatively higher level of co-presence.

- AR (real video) background conditions (C-AR, R-AR) significantly affected the level of co-presence.

- The character-like avatar presented in the AR (real video) environment showed relatively higher co-presence than the realistic character (with more resemblance to the actual corresponding person).

- The level of trust was significantly associated with the level of visual realism of the counterpart avatar, independent of the environment background type.

An MR-based teleconference or communication system should thus be configured according to the specific objective. For instance, in the case of casual multi-user games and social network services, the level of co-presence would be the important factor, and, therefore, the type of environment background. On the other hand, for teleconferences of serious business meetings, commercial transactions, and educational seminars, the level of trust, and the form of the avatar representation would be the deciding factor of its effectiveness.

5. Conclusions and Future Works

In this paper, we presented the effects of the type of the avatar (realistically reconstructed vs. character-like) and the background representation (real vs. virtual) on the participants' co-presence and trust with respect to the design of future VR/AR/MR communication systems.

As a result of our experiments, it was found that presenting the counterpart avatar in a real/AR background, even with just the basic facial and gestural features, improved the user's sense of sharing and being in the "same" space, whereas the visual realism of the correspondent was more important for eliciting trust toward him/her. These findings have implications for the design of multi-user communication and collaboration systems for different purposes.

Our study and findings can be further strengthened with improvements to the implementation, for example, with the visual and behavioral qualities of the reconstructed realistic avatar (e.g., visual artifacts and noise from the sensors, holes, etc.) and the character-like figure (e.g., natural animation, facial expression, gaze, blinking, lip-synching, etc.). As future work, we will continue to explore the effects of other related factors to improve the teleconference experience, for example, with respect to time of use/exposure, stereoscopy, lighting conditions, interaction, and places of the VR background. We also hope to employ

other physiological measures for assessing co-presence and trust more quantitatively and objectively such as the skin conductance, electroencephalogram, and electromyogram.

Acknowledgements

This work was supported by the ICT R&D program of MSIP/IITP (I5501-16-1016, Instant 3D based Join & Joy content technology), and also in part by the Basic Science Research Program of MSIP/NRF (No. 2011-0030079).

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