Improving Social Presence with a Virtual Human via Multimodal Physical–Virtual Interactivity in AR

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Abstract
In a social context where a real human interacts with a virtual human (VH) in the same space, one's sense of social/co-presence with the VH is an important factor for the quality of interaction and the VH's social influence to the human user in context. Although augmented reality (AR) enables the superposition of VHs in the real world, the resulting sense of social/co-presence is usually far lower than with a real human. In this paper, we introduce a research approach employing multimodal interactivity between the virtual environment and the physical world, where a VH and a human user are co-located, to improve the social/co-presence with the VH. A preliminary study suggests a promising effect on the sense of copresence with a VH when a subtle airflow from a real fan can blow a virtual paper and curtains next to the VH as a physical–virtual interactivity. Our approach can be generalized to support social/co-presence with any virtual contents in AR beyond the particular VH scenarios.

Author Keywords
Augmented reality; virtual human; social presence; copresence; physical–virtual interactivity; context-awareness.

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, Augmented, and Virtual Realities; J.4 [Social and Behavioral Sciences]: Psychology

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Figure 1: A concept of augmented reality (AR) from Microsoft Fragments. Top: A user can see virtual contents superimposed in the real environment through a Microsoft HoloLens headset. Bottom: The virtual content can be a virtual human sitting on a real sofa. https://www.microsoft.com/en-us/hololens/apps/fragments

Research Motivation and Background

A number of studies suggest that virtual/augmented reality (VR/AR) experience has a significant (psychological/social) influence on human users [14], which can change their emotions, thoughts, or behaviors even after the experience. VR/AR encounters a golden age with computationally powerful and compelling immersive wearable devices, e.g., head-mounted displays (HMD), and brings more potentials to influence our everyday life than ever. AR is particularly interesting in the way to merge virtual and real objects in a real environment and to run interactively in real time [2] (see Figure 1). The technology goes along with a wave of technical paradigm, *The Fourth Industrial Revolution*, which "is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres".[1] Along with high level of artificial intelligence (AI) and ubiquitous computing, such as internet of things (IoT), virtual contents in AR will collapse the real–virtual boundary and be absorbed as intelligent things or social companions that (socially) influence human users while mimicking physical affordances with a low social cost.

In this era, it is intuitively intriguing and important to study how we can make virtual contents more effective and efficient to provide strong *social influence* to human users, and how people perceive/understand virtual contents that they interact with in AR—where the contents appear to be present in the shared/co-located physical space.

In this paper, we are particularly interested in virtual humans (VH) as a form of intelligent virtual contents, which can make social influence towards the users by its presence in the shared space with the users. In many of training or simulation systems with VHs, the sense of social/co-presence with the VHs has been measured and associated to the system performance, e.g., how effectively or well real human users are trained so that they can do better in certain tasks after experiencing the system. Although AR superimposes VHs in the real world, the resulting sense of social/co-presence is usually far lower than with a real human due to the virtuality. Here, we introduce a research approach employing multimodal interactivity between the virtual environment and the physical world, where a VH and human users are co-located, to improve the social/co-presence of the VH in AR, and discuss about the effects and potentials with a preliminary study evaluation.

[1] Klaus Schwab, The Fourth Industrial Revolution: what it means, how to respond, World Economic Forum 2016. https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond

Related Work

This section provides an overview of related work on the concept of social/co-presence and VHs. In mediated interaction research, the sense of social/co-presence is an important measure to evaluate the quality of interaction and the potential social influence via the medium. While there is an ongoing debate in the research community about precise definitions, the concepts of *copresence* and *social presence* could be described as how one perceives another human's presence in a sense of "being together," and how much they feel "socially connected," respectively. Each of these concepts could be complementary to each other. Harms and Biocca [8] considered copresence as one of several sub-dimensions that embody social presence.

In VH research, the sense of social/co-presence with VHs is important because it could be directly associated with the VH system's performance and social influence towards human users. VHs have been used in many tasks where real humans are not ideal (or possible), or where the use of VHs is otherwise beneficial—medical/military simulations and social skill trainings are typical use cases. Rizzo et al. [16]

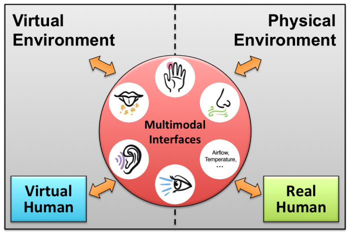

Figure 2: A concept of multimodal physical–virtual interactivity in a real–virtual human interaction considering the surrounding shared/mixed environments.

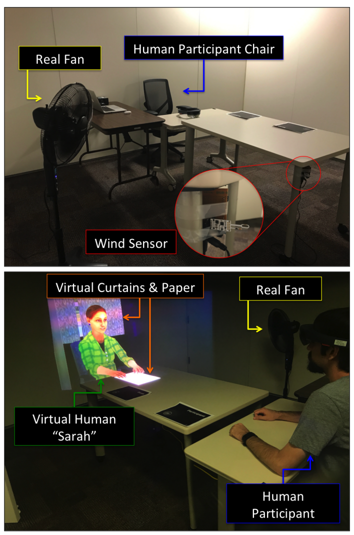

Figure 3: Experiment setup where a participant was seated opposite from a virtual human on a physical table. A wind sensor was used to detect airflow from a real fan that induced a virtual paper fluttering.

evaluated their autonomous VH platform that could recognize human user's verbal and nonverbal behaviors for identifying mental illness, and showed its potential in the certain medical/military applications. Hoque et al. [10] developed an interactive and expressive VH, and showed its effectiveness for a practice job interview. Huang et al. [11] also developed an autonomous virtual agent for an interview scenario, and used the level of social presence with the agent as a rapport measure. To increase the sense of social/co-presence, researchers have considered different aspects of VH's realism, e.g., its appearance [6] and verbal behaviors [15]. Holz et al. [9] provided a survey of various forms of agents in a fully physical, a fully virtual, or a mixed reality (MR) environment in the context of social interaction. They further detailed the benefits and issues of social interaction with virtual agents in different aspects, such as *interactive capacity*—an agent's ability to sense and act on the virtual or physical environment.

Research Approach

While a VH's appearance and verbal interaction is important to achieve a high level of social/co-presence, the VH's interactivity with the surroundings in the space where the interlocutors, i.e., a VH and a real human, interact with each other could be a critical factor influencing the sense of social/co-presence. Allwood [1] considered that the physical environment is one of the major parameters that characterize a social activity, and Blascovich [5] defined social presence as a "psychological state in which the individual perceives himself or herself as existing within an *interpersonal environment*" (emphasis added). The physical environment is particularly important in AR, where virtual content is visually merged with the real-world surroundings. In such environments, users might expect natural and seamless interaction between the virtual contents and the physical environment. Thus, we described unique characteristics of AR in environmental context and introduced a potential use of physical–virtual interactivity and VH's social behaviors, as an idea to improve the social/co-presence with the VH, in our previous paper [12]. The idea could make the AR (real–virtual) environment more seamless, and let the human users perceive that the VH's behaviors are more plausible or appropriate in the environment, which could eventually improve the sense of social/co-presense with the VH. Here, our research approach is based on the idea in two aspects: (i) multimodal physical–virtual interactivity and (ii) VH's environmental context-awareness (see Figure 2). In the approach, a VR system with a VH can sense environmental events happening in the physical space through multimodal interfaces, e.g., a temperature drop-down or a wind from a real fan. According to the sensing data/information, the system can adjust virtual contents in the space. For example, virtual frost can appear, or the VH can exhibit the awareness of the events by wearing a jacket due to the low temperature or looking at the fan blowing its hair. These can improve the level of social/co-presence due to the shared inter-personal environment [5] and the enhanced mutual awareness [7].

Preliminary Study and Evaluation

While exploring and investigating the effects of multimodal physical–virtual interactivity with several user studies (e.g., [13]), we have conducted a case study that involves environmental airflow events attempting to decrease the perceptual gap between physical and virtual spaces and a VH's awareness behaviors for the events. For the experiment, we implemented a VH that could speak and perform upper torso gestures via a Wizard-of-Oz control. The VH was displayed through a Microsoft HoloLens HMD, and was co-located with participants in an office-like AR space (see Figure 3), giving the participants an impression of being seated at a table across from the VH. A physical rotating

Condition	Physical Fan	Virtual Curtain & Paper Fluttering	Virtual Human's Environment Awareness Behavior (Holding Paper & Looking at Fan)
(A) Control	ON	NO	NO
(B) PVI	ON	YES	NO
(C) EAB	ON	YES	YES

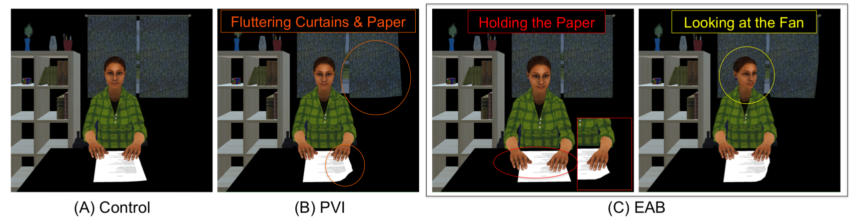

Figure 4: Experimental conditions. (A) Control, (B) PVI (orange circles: fluttering virtual paper and curtains), and (C) EAB (red circle: holding the paper gesture, red rectangle: less fluttering after holding, yellow circle: looking at the fan).

fan was placed next to the table and oriented such that the airflow would occasionally blow towards a virtual paper and curtains as the fan oscillated. A wind sensor[2], which was hidden below the table (red circles in Figure 3), detected the airflow, and allowed the virtual paper and curtains to flutter according to the real wind for three experimental conditions: (i) Control, (ii) Physical–Virtual Interactivity (PVI), and (iii) Environment-Aware Behavior (EAB). In the Control condition, the virtual paper on the table in front of the VH and virtual curtains behind her did not flutter, and the VH never demonstrated any awareness of the physical fan, while the virtual paper and curtains appeared to flutter as a result of the physical fan in the PVI condition, and the VH additionally occasionally exhibited attention toward the fan by looking at it or putting its hand on the virtual paper to stop the fluttering in the EAB condition (see Figure 4). In all conditions, the VH had a brief verbal interaction with the participants asking personal questions.[3] For the preliminary evaluation, 17 participants (9 females; age M=21.4, range: 18–37) from our university community experienced three experimental conditions in a randomized order, and their sense of copresence with the VH was measured through five questions in 7-point Likert scales (see Table 1), which were extracted and modified from existing questionnaires [3, 4].

Table 1: Copresence questionnaire used in the experiment.

Co-Presence (Sense of Being Together in the Same Place)
• I perceived that I was in the presence of the person in the room with me.
• I felt the person was watching me and was aware of my presence.
• I would feel startled if the person came closer to me.
• To what extent did you have a sense of being with the person?
• To what extent was this like you were in the same room with the person?

Considering sample size, dependency, and ordinal characteristics of the questionnaire responses, a non-parametric Friedman test was used for the analysis of the reported copresence scores, and we found a significant main effect of the experimental conditions, $\chi^2(2) = 7.300, p = .026$ (see Table 2). The magnitudes indicate a higher copresence for the PVI and the EAB conditions than the Control condition, and suggest that mere peripheral environmental events, such as fan-blowing objects and VH's awareness

[2]Modern Device Wind Sensor Rev. P. https://moderndevice.com/product/wind-sensor-rev-p

[3]For the verbal interaction with the VH, thirty questions, e.g., "When is your birthday?" were extracted from http://allysrandomage.blogspot.com/2007/06/101-random-questions.html (Accessed 2017-12-16).

	Mean Rank	Median
Control	1.50	3.33
PVI	2.21	3.83
EAB	2.29	3.67
N		17
Chi-Square		7.300
df		2
Asymp. Sig.		**.026**

Table 2: Friedman test results for copresence.

Promising Virtual Human Applications: Training/simulation applications with VHs can benefit directly from the outcome of our research approach with the increased social/co-presence.

Social Psychology Knowledge with AR Contents: In a broad sense, we can understand how people perceive and understand virtual contents in AR in terms of its social context and presence.

Realistic AR Contents: Multimodal physical–virtual interface can make AR contents authentic and plausible in the environment, which could potentially reduces social cost.

behaviors by observing them, impact one's sense of copresence with the VH that they interact with. This could provide a useful reference for practitioners who want to increase the copresence level by physical–virtual environmental interactivity via the shared airflow.

Research Novelty and Contributions

In this paper, we introduced a multimodal physical–virtual interactivity approach to improve the sense of social/copresence with a VH, and described a preliminary human-subject study in which we analyzed the effects that physical–virtual connectivity and awareness behaviors can have on the sense of copresence with a VH in AR. We demonstrated that subtle environmental events related to airflow caused by a physical fan can lead to higher subjective estimates of copresence with the VH. Although some research use multimodal sensing data to build a realistic VR systems, they are usually limited to visual and aural cues. Our approach is novel in the way that we attempt to utilize various possible modalities, such as olfactory and tactile, and we consider social aspects with virtual contents.

The potential contributions of our approach are directly on understanding of how people perceive a VH in social context and improving the VH's social influence to human users by improving the sense of social/co-presence; however, the contributions can be applied to generic virtual contents in AR/MR beyond VHs. In future work, we plan to investigate other modalities to increase the dynamics and fidelity of interaction between the real and virtual spaces in AR, and adapt the findings to develop a promising virtual contents.

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