What Comes After Telepresence? Embodiment, Social Presence and Transporting One's Functional and Social Self

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***Abstract*—Advances in robotics and multisensory displays allow extending telepresence ambitions beyond only "the feeling of being present at a remote location". In this paper, we discuss what may lie beyond telepresence and how we can transport both the functional and social self of a user. We introduce the embodiment illusion and its potential contribution to task performance and list important cues to evoke this illusion, including synchronicity in multisensory information, a first-person visual perspective, and a human-like visual appearance and anatomy of the telepresence robot. We also introduce the concept of social presence and the important bidirectional social cues it needs, including eye contact, facial expression, posture, gestures, and social touch. For all these multisensory and social cues, we explain how they can be implemented in a telepresence system and describe our solution consisting of a closed control pod and a humanoid telepresence robot.**

***Keywords*—telepresence, embodiment, avatar, robotics, tele-operation**

I. Introduction

Telepresence refers to the feeling of being at another location than one's physical body (see Table 1 for a glossary of main concepts). Traditionally, telepresence has been achieved by presenting images and sounds of remote cameras and microphones to a user through a Head Mounted Display (HMD) and a (stereo) headset. Control of the remote sensors –if possible– is coupled to head movements, and the remote sensors can be mounted on a robotic platform to make them mobile. These telepresence systems have been used in remote inspection, education, operation of machines, explosive ordnance disposal, and entertainment. Although they can indeed evoke a feeling of telepresence, some may argue that such a basic setup is not very immersive or realistic, as only two senses (vision and audition) are typically stimulated and only in a limited way.

Because of the recent advances in robotics, mobile networks, and multisensory displays, the time is ripe for the next generation of telepresence systems. This entails that we may need to reconsider our ambitions with respect to telepresence, leading to our goal to achieve a sense of embodiment. Embodiment refers to the ensemble of sensations of having and controlling a surrogate such as a robotic device, a virtual avatar, or a mannequin [1]. In addition, new application domains may open up, for instance by mediating social interaction.

TABLE I. GLOSSARY OF MAIN CONCEPTS.

Telepresence: the feeling of being at another location than one's physical body.
Embodiment: the feeling of external objects (for instance a rubber arm or a virtual or robotic avatar) being (part of) one's body.
Social presence in mediated social communication: the feeling of having an affective and intellectual connection with another person, related to perceived mutual proximity, intimacy, credibility, reasoning, and behavior of the communication partners.
Spatial presence in mediated social communication: the feeling of being physically together with another person.

The main goal of the first generation telepresence systems was to transport one's functional self to a remote location. One's functional self is related to spatial presence, task performance, and interacting with objects in the environment. This reflects the traditional application area of telepresence: operating in harsh and often uninhabited areas. However, there are also telepresence applications that include an important social aspect. Examples include visiting a relative, care-taking, or lending one's expertise as we currently do in a limited way through videoconferencing. Therefore, we are also interested in transporting one's social self and the feeling of social presence, i.e. to interact with and feel connected to people in remote environments. The feeling of social presence is inherently bidirectional: people in the remote environment should feel socially connected to the remote user and vice versa.

In order to formulate and categorize the requirements that different telepresence applications may have, Table 2 presents some key characteristics and differences between systems primarily intended to transport either one's functional self or one's social self (although these are not mutually exclusive).

In Section III, we will focus on the importance of the feelings of embodiment and social presence as expansions of the feeling of telepresence. In Section IV, we will discuss how embodiment and social presence drive the requirements for the next generation of telepresence systems and how we implemented them in an operational telepresence system. We discuss the approach and the inherent risks of going beyond telepresence in Section V.

TABLE II. MAIN CHARACTERISTICS AND DIFFERENCES OF TELEPRESENCE SYSTEMS PREDOMINANTLY AIMING TO TRANSPORT ONE'S FUNCTIONAL SELF OR ONE'S SOCIAL SELF.

Transport one's functional self	Transport one's social self
Spatial presence	Social presence
Task performance and feeling in control	Feeling connected
Interacting with objects	Interacting with people
Situational awareness	Social cues
Predominantly unidirectional	Inherently bidirectional
Safe and trustworthy technology	Additional focus on mutual, inter-human trust

II. RELATED WORK

The interest in telepresence systems has strongly increased over the past years and the global Covid-19 pandemic and resulting restrictions on traveling and social interaction have provided an additional boost. As a result, we can refer to several recent review articles for the relevant work done in different applications. For instance, [2] reviewed telepresence applications in dangerous environments and concluded that telepresence through sufficient visual and force feedback has positive effects on performance. Reference [3] looked at applications in clinical care and concluded that technology can significantly improve the quality of care, but also advised that ethical issues should be better explored. However, [4] adds that current robotic systems are mainly equipped with visual and auditory sensors and actuators –if present– that only have a limited capability in performing health assessments.

Related to transporting one's social self, [5] and [6] concluded that the (still limited) literature suggests that telepresence robots have potential utility for improving social connectedness of people and their caregivers. References [7, 8] underlined the usefulness of telepresence in education, especially for students with special needs, but also argued that improvements to the design of telepresence robots are required to maximize educational and social benefits.

In [9], the authors introduce a framework for mediated social communication (holistic mediated social communication: H-MSC) in which they disentangle spatial presence and social presence (see Table 1). We will use this H-MSC framework in the next section.

III. FROM TELEPRESENCE TO EMBODIMENT AND SOCIAL PRESENCE

Telepresence refers to the feeling of being at a different location than one's physical body. We have a clear goal to use novel technologies to go beyond 'just' the feeling of being present at a remote location and explicitly look at embodiment and social presence.

A. *Embodiment*

Embodiment is not just the feeling that you are at a different location than your physical body, but also the feeling that you -almost literally- crawl into the robotic system: the robotic body becomes your own body, its microphones and cameras become your ears and eyes, the robot arms and hands become your arms and hands, etc. Embodiment has been studied extensively from cognitive and neuroscientific perspectives. These studies show that under certain conditions, the human brain can accept an external object as part of one's own body. This external object can be anything, including a rubber hand, which is often used in this kind of studies, also referred to as the Rubber Hand Illusion [10]. The illusion that a rubber hand is one's own hand is simply evoked by blocking the direct view of one's own hand, and synchronous stroking of the (invisible) own hand and the rubber hand. The embodiment illusion can become stronger if more synchronous sensory cues are added [11].

An important question is why an embodiment illusion is relevant for the next generation telepresence systems. Embodiment consists of three components: 1. the sense of *ownership*: the feeling of self-attribution of an external object or device, or the extent to which one feels the telepresence robot to be one's own; 2. the sense of *agency*: the extent to which one -and nothing or nobody else- controls the telepresence robot’s motions; 3. the sense of *self-location*: the extent to which one considers the telepresence robot’s location as one’s own location [12]. All three components can influence task performance and there is indeed evidence that higher levels of embodiment lead to improved task performance [13, 14], although the robustness of this relation is still unclear. In addition, embodiment may be considered as ultimate transparency: the feeling that you *are* the telepresence robot implies that there is no longer a mediating device. This ultimate transparency may lead to lower cognitive workload and faster learning [15].

A key question is how to evoke embodiment in a telepresence setting. Embodiment is a complex interaction between top-down expectations about one’s own body and bottom-up sensory cues. The key sensory cues relevant in telepresence are listed in Table 3 and a telepresence system should be designed to support the optimal conditions to evoke the embodiment illusion. It is important to note that not all cues have the same importance (or weight) in evoking the illusion. A recent study [16] showed the following rank order of the five cues it investigated: visual-motor-proprioception synchrony, tactile feedback, visual appearance, connection between the body parts, and finally field of view. It should also be noted that none of the cues is a prerequisite to evoke the embodiment illusion. This implies that even the absence of a key cue can be compensated by the presence of other, less important, cues.

TABLE III. IMPORTANT SENSORY CUES TO EVOKE THE EMBODIMENT ILLUSION.

Sensory cue	Optimal condition to evoke embodiment
Point of view	First-person perspective, meaning that the cameras should be positioned ‘anatomically’ correct in the telepresence robot
Posture	Robot postures that comply with human anatomy, i.e. without twisted arms, etc.
Visual-motor-proprioception synchrony	A telepresence robot that moves in synchrony with the operator’s movements
Connection between body parts	Parts of the telepresence robot should be connected in a natural and believable way
Visual-tactile synchrony	Vision and touch of objects contacting the telepresence robot should be congruent in time, space and meaning
Visual appearance	The telepresence robot looks human-like with human-like proportions

B. Social presence

More recent promises for telepresence technology concern mediated social interaction, or technology to transport one’s social self to a remote location. In addition to embodiment and spatial presence, we need to focus on the concept of social presence, defined as “sense of being with another in a mediated environment” [17] or the sense that another person is “real” and “there” when using a communication medium [18, 19]. It is generally accepted that mediated communication results in a lower sense of social presence than face-to-face communication, but the extent depends on the medium and the social cues it can communicate (e.g. see [20]). Social presence requires different cues than spatial presence. For instance, touch for social interaction is different from touch to grab and manipulate an object [21, 22, 23] and vision to read facial expressions is quite different from vision to build spatial awareness of the environment. In addition, social interaction is inherently bidirectional. One must be able to read the social cues of the people in the remote environment, but the people in that environment must also be able to read one’s social signals displayed through the telepresence robot. Table 4 presents an overview of relevant, non-verbal cues in mediated social interaction, roughly ordered from critical to less important [24].

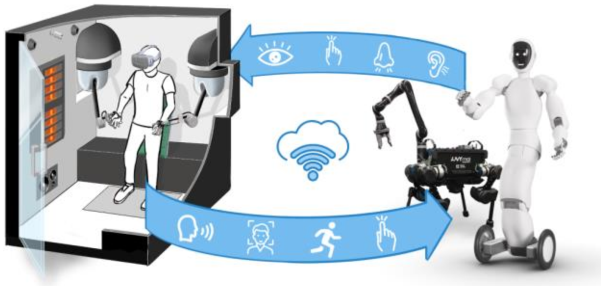

Fig. 1. Schematic layout of the telepresence system with the control pod on the left and the telepresence robot on the right. The closed pod blocks the sensory cues of the local environment and displays the cues of the remote environment (including vision, touch,audition and olfaction) to the user. The user’s head, eyes, arms, fingers, upper body and feet are tracked to control the humanoid robot.

C. Relation between embodiment and social pressence

Based on the H-MSC framework [9], it is likely that embodiment in a robotic avatar and social presence are not independent. The H-MSC framework defines quality of social presence at five levels of which three (sensory, affective/emotional and cognitive) have a link to embodiment in a robotic avatar. At the sensory level, users should have the impression that they are in direct contact with each other (physical immediacy or the illusion of non-mediation. At this level, the avatar can increase the feeling that the represented individuals are in one’s physical proximity or direct influence sphere (the feeling that one can make direct physical contact). At the affective / emotional level, the mediated representation of an individual should convey and evoke similar emotions as its unmediated counterpart and the avatar helps to create an emotional and intellectual connection with the represented individual. Finally, at the cognitive level, the represented individuals should look as in normal life and the avatar can create a natural or at least credible appearance of the represented individuals.

IV. IMPLEMENTATION IN A TELEPRESENCE SYSTEM

Tables 3 and 4 served as starting point for the development of the telepresence system shown in Fig. 1 that consists of two main parts: a closed control station (left) and a humanoid robot in the remote environment (right). The humanoid robot is based on a Halodi Eve robot (Halodi Robotics, Moss, Norway). The control station is housed in a closed shell and referred to as control pod in this paper. The control pod is a custom design based on a Sensiks Sensory Reality Pod (Sensiks, Amsterdam, the Netherlands) and blocks cues from the local environment that would otherwise disturb or even break the illusion of being present in the remote location. The control pod currently has displays for vision, audition, force (arms and fingers), touch (hands), smell, temperature (ambient and on the hands), and wind; and controls for fingers, arms, head, eyes, mouth, posture, and translational and rotational movements of the robot. Fig. 2 depicts a user inside the pod controlling the robot located in a remote kitchen.

TABLE IV. IMPORTANT SOCIAL CUES TO EVOKE SOCIAL PRESENCE.

Social cue	Optimal condition to evoke social presence
Eye contact	Gaze on-camera increases likeability, social presence, and interpersonal attraction [25]. The cameras on the telepresence robot should be close to the depicted eyes
Facial Expression	The areas around the mouth and eyes are important to read facial expressions. The telepresence robot should provide good representation and visibility of these facial areas
Non-verbal sounds	The bidirectional sound communication should be able to communicate non-verbal sounds in addition to speech
Eye gaze and blinks	Gaze patterns and blinks are important in social interaction (e.g. see [26] for a review). The telepresence robot must accurately display the gaze patterns and eye blinks in addition to only eye contact
Gestures, movement, orientation, posture	Gestures, movement and posture involve the whole body (e.g. waving, nodding, bowing, hand signals, inter feet distance, etc. see [27, 28]. A telepresence robot must be able to replicate these whole body signals beyond head and arm movements
Touch	Social touch is primarily a non-verbal bidirectional social cue (e.g. handshake, hug, tap on the shoulder [23]). The telepresence robot should both be able to provide a social touch to the people in the remote environment and to receive social touches from them
Proximity, personal space	Personal space refers to the physical distance to others required for someone to feel comfortable [29]. The perceived (bidirectional) proximity using a telepresence robot should be identical to that in real life

Minimal physical connections from the system to the user ensure optimal freedom of movement. The user only wears a wired HMD (HTC Vive Pro Eye, HTC Corporation, Xindian, New Taipei, Taiwan) and a hand exoskeleton (Haption H-Glove) that is attached to the haptic control interfaces (Haption Virtuoses (6D)), both by Haption GmbH, Aachen, Germany. This minimizes the time needed for donning and doffing and any experience of intrusiveness.

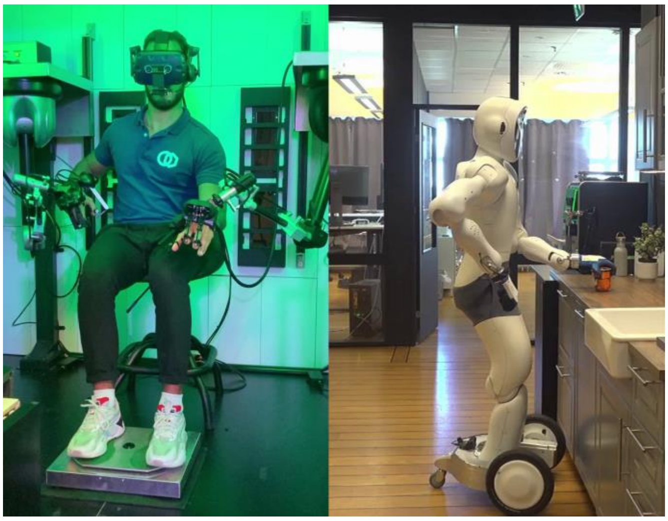

Fig. 2. The user inside the pod (left panel) controlling the humanoid telepresence robot on the right in a kitchen 800 km away.

TABLE V. IMPORTANT SENSORY CUES TO EVOKE THE EMBODIMENT ILLUSION AND THEIR IMPLEMENTATION IN THE TELEPRESENCE ROBOT AND CONTROL POD.

Sensory cue	Implementation
Point of view	An extended reality (XR) setup with an HMD is used to virtually place the operator inside the remote robot. The XR environment consists of 1) vision through a ZED Stereo camera (ZED 2, Sterolabs Inc., San Francisco, CA) at the eye position of the humanoid robot and 2) a VR model of the robot and the environment for (self-)view outside the camera's field of view. Additionally, the VR model can trigger e.g. the release of scent, activate airflow or switch heaters on and off (all custom made for the control pod)
Posture	Movements of the robot are restricted to the human anatomical boundaries
Visual-motor-proprioception synchrony	Movements of the user are directly coupled to movements of the corresponding body parts of the robot (head, arms, hands, upper body, etc.) as can also be seen through visual feedback
Connection between body parts	The humanoid robot is close to anatomically correct, including joints and degrees of freedom of motion
Visual-tactile synchrony	All sensory cues, including vision, audition, touch, temperature, airflow and smell are synchronised
Visual appearance	The humanoid robot resembles the autonomy of a human with a height of 1.85m and the robot's motions resemble those of a human

TABLE VI. IMPORTANT CUES IN SOCIAL INTERACTION AND THEIR IMPLEMENTATION IN THE TELEPRESENCE ROBOT AND CONTROL POD.

Social cue	Implementation
Eye contact	The cameras on the telepresence robot are close to the depicted eyes, but slightly above. This position is preferred in case eyes and cameras are not collocated [25]
Facial Expression	The robot has displays that depict a B/W pictorial display of the mouth and eyes at the anatomically correct position in the robot's head. The B/W pictorial display helps to avoid feelings of uncanniness, that can more readily occur with a colour/lifelike representation of the user's face. Blinking and eye movements of the user are tracked through the eye tracker in the HMD and used to control the pictorial display in the robot. Mouth movements of the user are tracked by a camera mounted on the HMD and directed at the user's mouth and used to control the pictorial display in the robot
Non-verbal sounds	The bidirectional sound is provided by a Jabra system (Jabra Speak 510, Copenhagen, Denmark) on the robot and a build-in microphone and headset of the HMD
Eye gaze	Gaze direction of the user is tracked through the eye tracker in the HMD and depicted through the pictorial eye display on the robot
Gestures, movement, orientation, posture	The robot has 23 degrees of freedom. Close-to direct-drive transmission technology allows for easy interactions and fast and accurate motions. Movements of the user's arms, hands, and fingers are tracked and coupled to that of the robot. Head motions are tracked through the HMD. The user's upper body movements (forward-backward, left-right, and rotations) are tracked through a tracker on the chest (HTC Corporation, Xindian, New Taipei, Taiwan), lower body movement (crouching) is coupled to the hand position of the user (i.e. lowering the hands below their normal low position (e.g. by bending the knees) controls the crouching motions of the robot

Social cue	Implementation
Touch	Currently, only force feedback in arms and hands is implemented. The user can thus feel the forces of for instance a handshake. A touch-sensitive skin and a whole-body haptic suit are currently under development. Ambient heat sources are detected through four IR sensors on the robot and displayed through six directional heaters in the control pod
Proximity, personal space	Camera placement, VR rendering of the robot body and the anatomically correct sizes of the robot all help to support the perception of proximity of other people

A. Informal evaluation

The universal pod was developed by means of a user-centric design approach to ensure that a novice user can operate the system and enjoy the complete immersive experience without extensive training. We have developed a specialized training protocol that requires less than 30 minutes to complete and that allows the user to interact with objects and people in the remote environment in an intuitive way, for instance, to do a cooperative puzzle task as depicted in Fig. 3. Informal evaluations with eight naïve users confirm that the system is easy to learn, results in a high level of telepresence and embodiment, and allows users to feel socially connected with people at a distance. We will complete formal evaluations in the near future.

Fig. 3. Interaction between someone in the remote environment and the user present through the telepresence robot. They are working together to complete puzzle.

V. Discussion

Enabling experts to apply their skills anywhere instantaneously offers a great impact in terms of safety and efficiency. This applies to, for example, inspection and maintenance, care, and education. The market for telepresence robots is expected to grow. For instance, RIMA's (Robotics for Inspection and Maintenance) 2020 Global Market Overview (https://rimanetwork.eu/) expects a consistent 15-20% annual growth of robotics for inspection and maintenance.

In this paper, we explain our ambitions that go beyond telepresence: we aim to transport both the functional and social self of a user. We introduced the embodiment illusion and the importance of bottom-up, multisensory cues in achieving this illusion. Our approach to embodiment therefore goes beyond vision and audition and includes haptics, touch, temperature, smell, and airflow. Generally speaking, affording more sensory cues results in better spatial presence, better task performance, a more robust illusion of embodiment and telepresence, and better interaction with the environment and the objects and people therein.

Next, we introduced social presence and the importance of bidirectional social cues in achieving this effect. Our approach is to enable people in the remote environment to make eye contact with the user, to read the facial expressions of the user, and to determine the gaze direction of the user. In addition, the user's non-verbal sounds, gestures, movements and posture are displayed to the people in the remote environment through the humanoid robot, and the user can perceive the cues needed to maintain personal space.

Our vision is that most impact can be made by using fit-for-purpose telepresence robots as opposed to a generic robot that is applicable to the complete range of telepresence scenarios. The capability to transport both one's functional and social self requires a modular design approach, which allows for example to control different types of robotic systems from the same (universal) control pod. We can switch between the humanoid robot Eve and an animal-like legged robot (ANYmal C, ANYbotics, Zurich, Switzerland), both controlled from the control pod described in this paper, in less than 30 seconds. See also Fig. 1.

Telepresence technology can affect many features of our lives, including economic, social, and cultural aspects, and it may change social systems, norms, and regulations. It will provide new opportunities but also carries inherent risks, both for individuals and for societies. Examples include:

- The labor market: workers from low-income countries can work in other countries without migrating.
- Education: access to rich educational environments with the best teachers from anywhere in the world.
- Health: improved quality of care by experts at a distance, but also the introduction of cybersickness, isolation, mental illness, cyberbullying, and addiction.
- Social interaction: high quality of mediated social interaction, but a reduction of direct human to human contact [30].
- Security: hacking, spoofing, deep fakes, etc. can make one believe to be interacting with someone different.
- Safety: partly driven by anonymity, users controlling the telepresence robot may violate social rules, invade personal space, engage in sexual harassment, commit crimes, etc. It can be expected that users can even go beyond what happens in digital space, which already drove tech companies to bring in countermeasures such as options for mandatory distances between avatars in VR. In addition, a high degree of embodiment might magnify the psychological impact of violating social rules by people in the environment toward the robot, including sexual harassment.

- Inequality: increased gap between the 'haves' and the 'have nots', exclusion of digital illiterates.
- Privacy: telepresence robots can invade the privacy of one's own home.
- Cyberbullying: telepresence robots may lead to embodied cyberbullying.

We believe that researchers and technology developers should actively seek the debate on ethical, legal and societal issues of telepresence technology.

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