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Mediated Touch: Exploring embodied design for remote presence

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Abstract. In this paper, we present a novel telepresence system, which consists of audio, video, haptic, and kinetic modules. The haptic and kinetic modules allow us to explore mediated touch. We conducted an initial survey of user reactions, which lead us to conclude that social meaning and the emotional significance of touch can be preserved in a mediated setting. User feedback also leads us to believe that we were successful in designing a system which allowed participants to experience an embodiment relation to the remote environment. The factors that we determined as important for the success of such a design are a close coupling between mediated touch and audiovisual cues as well as clear relations between stimuli chosen for inputs and outputs of the system. Finally, we conclude that an embodied experience is easier to design when creating new sensations, rather than aiming to mimic known experiences.

Keywords. Telepresence; Robotics; Haptics; Mediation; Embodiment

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Introduction

With the increasing ubiquity of robots in our society, the concept of telerobotics is slowly receiving more attention. Commercially available telerobots, however, diverge widely from early visions of telerobotic systems. These systems were originally envisioned in a style that drew heavily on embodiment relations, a close coupling between input and output, and immersion (i.e. Heinlein, 1942; Saberhagen, 1969; Minsky, 1980). Today commercially available telerobots are often based on tablet computers or smartphones with added hardware, which gives the system additional mobility[1]. Other systems use custom display and video devices on more sophisticated mobile platforms[2]. These telerobotics systems do not offer a remote user any method of directly manipulating the local environment or directly manipulating the telerobot. Lacking the immersion of early utopian visions, commercial telepresence robots today strongly rely on hermeneutic relations between users and technology and between users and the world through the robot. Hermeneutic relations require the user to *interpret* information about the remote location and the robots position within it, rather than enabling the user to directly *experience* this information.

[1] i.e. http://www.gizmag.com/kubi-telepresence-robot-tablets/25389/
[2] i.e. http://www.doublerobotics.com/

In this paper, we explore the design of an embodied experience of remote presence. We distinguish between presence and remote presence: With presence we mean the experience of physically being in a place. When we refer to remote presence we mean this very experience, but occurring at a different location from the physical body. We use the term *embodied experience* to indicate that the user should not be required to interpret any stimuli in order to understand their remote presence, but should literally feel present in the remote location.

We evaluate our system with a preliminary user study. In this study we compare unmediated touch to mediated touch. We also compare two different methods of implementing mediated touch. Mediated touch is especially interesting to us, because it is less burdened by pre-existing social protocols and mental models than mediated images, text or audio. If, for example, we were to focus our analysis on the audio link, chances are that any effect we might observe would not be caused by the user's reaction to the telerobtic system, but rather by the user's adherence to preexisting communication protocols. We therefore believe the users reactions to mediated touch to be indicative of the overall qualities of our telepresence system.

Related Work

Our initial interest was in exploring mediated touch. Systems such as InTouch (Brave & Dahley, 1997) provide an abstract object as a means for mediated kinetic interaction. Norman White (Shanken, 2000) presented a less abstract approach: his robotic arm wrestling system enables two individuals to remotely arm-wrestle using robotic arms. Similar to White's arm wrestling system, we were interested in designing around physical experiences of the body. Unlike White, however, we focused on more subtle interactions, such as a casual touch.

There are a number of systems that explore this design space. Hug Over A Distance by Mueller (Mueller et al., 2005) allows a user to touch a teddy-bear, which in turn inflates a vest worn by another person, emulating a hug. Casual touches are explored in great detail by Haans and IJsselsteijn (2008; 2005; Haans, Nood, & IJsselsteijn, 2007), who attempted to discover whether psychological effects of touch can be recreated by mediated touch.

We specifically decided to explore the mediation of haptic sensations as a tool for exploring presence. We stipulate that comparing the effects of mediated to non mediated touch can inform us on our success in creating an embodied experience of remote presence. Attempts to evaluate non-mediated touch interactions in an HCI context, as was explored with DoNotTouch & TagUrIt (Cheng & Dickie, 2011; Cheng, Kim, & Vertegaal, 2011) are therefore interesting points of reference to compare to our own work.

We draw on (post)phenomenology to provide us with a vocabulary to discuss the phenomenas of interest. When Heidegger (2000) discusses the use of tools, he points out that a hammer, once it is in use, transitions from a state as a mere object to becoming part of one's agency in the world. In his words, it transitions from being 'vorhanden' to being 'zu handen'. Merleau-Ponty (1945) observes a similar phenomenon and describes that we expand our range of perception through objects, like a blind person does with a cane, and in the process, the object becomes embodied. Ihde (1990) reworked these ideas in a postphenomenological position that aims to to overcome the subject/object dichotomy. He systematizes these observations into a system of relations divided into background relations, alterity relations, and relations of mediation. Like Verbeek (1992), who uses this taxonomy to evaluate contemporary design practice, demonstrating how these terms are relevant in contemporary industrial design, we also draw on Ihdes system of relations to better understand our design process and evaluation.

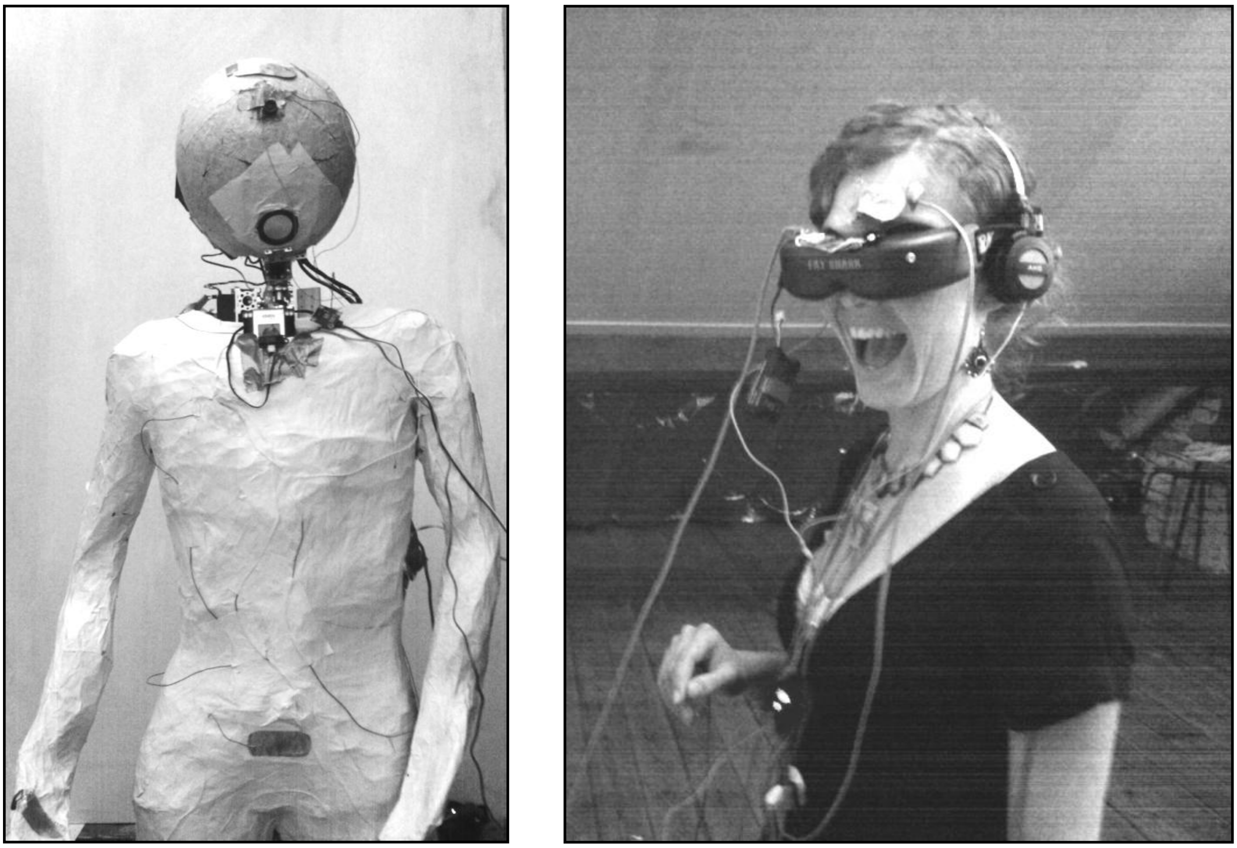

Figure 1. a) Telepresence Robot (remote system) b) interface (local system)

Design Rationale

We set out to design a robotic telepresence system that enables embodiment relations, a close coupling between input and output, and immersion. This was in part inspired by Ihdes' (1990) taxonomy of technological mediation. Ihde speaks of alterity relations, a relationship towards things experienced as 'an other', including robotic telephone operators or any machine that seems to follow its own dynamics rather than strictly reacting to user input. Background relations are relations that mediate the setting we are in, without ever becoming the focus of the attention; Ihde describes one's relation to an air-conditioner, which adjusts the temperature without users consciously noting it, as a prime example. Finally, Ihde speaks of two types of relations of mediation: hermeneutic relations and embodiment relations. The difference between these relations is, again, best illustrated by example. If you are interested in the temperature outside, you can experience it hermeneutically by checking the temperature on a thermometer, or you can open the window for an embodied experience of the same information.

In our observation, a large number of current telepresence systems rely heavily on hermeneutic mediations, and we are not aware of any systems that are specifically designed for embodiment relations. Following this, we designed a system around the concept of embodiment, and to understand what it would mean to users to interact through such a system. Both our design and evaluation focus mainly on mediation of touch. The reason for that is two-fold. On the one hand we believe that haptic and kinetic sensations are extremely important, if not essential for embodiment relations. On the other hand, exploring haptics and mediated touch allows us to work with a medium in which interactions are not yet dictated by an established social protocol.

Implementation[3]

Our system is divided geographically into the local and remote elements. The local system consists of a robot (figure 1a) with which the local user interacts. The remote system (figure 1b) consists of the equipment that the remote user wears to operate the robot. The system is further divided into audio, video, haptic, and kinetic modules.

> The ***audio module*** is purely analog. It presents the remote user with stereo sounds from the robots location. It also records the remote user and plays back the remote users voice from a mono speaker in the robots head. We use two Edirol R-09HR recorders as stereo microphones and preamps, which are directly connected to headphones (for the remote user) and the speaker located in the head of the robot.
>
> The ***video module*** is also analog, and consists of a ¼" 420TVL CMOS camera placed on the robots head, which is connected via a direct radio link to FatShirk video-goggles. This enables the remote participant to see the local location from the robots perspective.
>
> The ***haptic module*** enables the remote user to feel vibrations when the robot is touched, or when someone is in close proximity of the robot. It consists of 8 capacitive touch areas and one infrared (IR) proximity sensor which are mounted on the robot and continuously sampled by an Arduino microcontroller. The Arduino is connected to a local computer. The local computer sends the sensor readings as Open Sound Control (OSC) network messages to the remote computer. The remote computer sends the values to an Arduino that controls 9 vibration motors attached to the remote users body.
>
> Finally, the ***kinetic module*** tracks the remote users head movements and controls the robots head, so that the robots head is always oriented the same way the remote uses head is oriented. It consists of a 9 degrees of freedom inertial measurement unit attached to the FatShark video goggles. This sensor is attached to another Arduino that reads the values and calculates the relative movement of the goggles.

These values are sent to the local computer via the remote computer. The local computer in turn sends them to an Arduino. These values are sent to the local computer via the remote computer. The local computer in turn sends them to an Arduino that controls the servo motion of the robot's head (the full setup can also be seen in figure 2).

Initial Reactions to the System

Although we define presence as a physical experience, and therefore potentially measurable in the physical world, it is also an active and personal experience, one that we believe is best accessed through ethnographical methods. For this reason, we decided to rely on self-report and observation. We created a quasi-experimental setup with three tasks.

> In **task 1**, we asked pairs of participants to touch each other on 8 indicated areas of the body (figure 3). The participants were shown where these areas are and subsequently asked to touch, poke, and finally, touch these areas 'intensely'.
>
> In **task 2**, (figure 2) we asked participants to interact with each other through the robot; the local participant again touching the remote participant on the same 8 areas. We all-

[3] For videos as well as additional information, please visit www.paulstrohmeier.info/mediatedtouch

Figure 2. User Interaction with the system.

owed the participants to go about this in whatever manner they pleased. If the interaction stalled, however, we would offer them scenarios that they could re-enact. We also ensured that all touch areas were touched at least once.

Finally, in **task 3**, we replaced the 8 touch sensors with one IR proximity sensor corresponding to a single vibration motor located on the remote users chest, and repeated the same procedure.

Between tasks, participants were asked to fill in questionnaires about the preceding task. During the tasks, we would talk with the participants; if we observed unexpected or interesting behavior, we would inquire about it, asking the subjects to explain what they were doing and why.

We compared task 1 and task 2 to gain understanding about what is mediated through the vibration / touch sensor link. The participants were asked to rank the touch points from most appropriate to least appropriate, and then to rate the individual touch points on their appropriateness. We propose that, if the results of the ranking were significantly different, this would mean that none of the social rules that relate to touch remained present in the mediated condition. Our second assumption is that if the ratings were significantly different, this would mean that the emotional impact of touch between the conditions is also different. As a control, we stipulate an auxiliary hypothesis: the location of the touch point will have a significant effect on how it is ranked and rated (the locations of the touch points are indicate with circles shown in figure 3).

Comparing task 2 and 3 was also of interest to us, as it might help to inform future design choices. We asked participants to fill out 16 five point Likert items, which we summed and rescaled into two Likert scales representing the extent to which the participants felt an embodied mediation and hermeneutic mediation respectively. Based on our intuition, we assumed that the proximity / vibrator link would lead to a stronger feeling of embodiment than the touch sensor / vibrator link. Finally, we did not restrict our inquiry to these three questions, but merely used these as guidelines to structure our observations and questions.

Our participants were predominantly female (14 of 18) and their median age was 24. The participants were of varied cultural background (Spanish, Dutch, Austrian, Belgian, German, Phillipine, Friench, Indian, British). They were recruited via word of mouth in the Mandril Cultural Center in Maastricht, the Netherlands. All except for two participants were students.

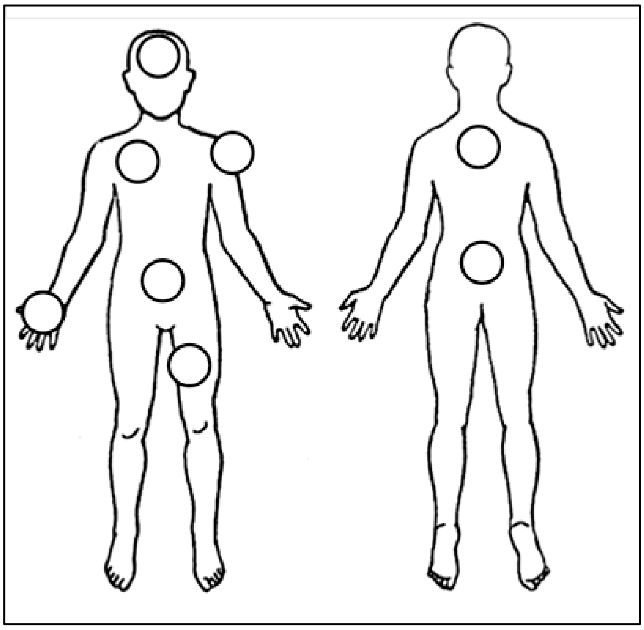

Figure 3. Location of Touch-Points.

Results (Task 1 & Task 2)

We conducted a repeated-measures factorial ANOVA on the aligned rank transforms of both the touch-point ranking and ratings, as suggested by Wobbrock (2011). As expected, we found a significant effect of touch-point location on both rankings ($F_{7,105} = 32.903$, $p < 0.001$) and ratings ($F_{7,105} = 19.854$, $p < 0.001$), which means that some touch points were considered to be in more appropriate locations than others. Not completely unexpected, we did not find a significant effect of the type of touch (physical or mediated) on the rankings (A), suggesting that social norms of touch might be preserved in the mediated condition. Somewhat to our surprise, we also found that there was no effect of type of touch (physical or mediated) for the ratings (B), suggesting that the emotional impact of the mediated touch might be similar to the non-mediated condition (table 1).

Looking at the most common responses (table 2, mode), the ranking between task 1 and task 2 appears similar. The main exception is the ranking of the lower back. This could be explained by the fact that the lower back was difficult to reach on the robot, and therefore the local participants hardly ever touched it. The ratings (B) are similar as well, with the thigh clearly the least appropriate area to touch. The mediated condition (task 2), however, is clearly considered to be more appropriate to touch than the unmediated condition (task 1). We believe this because some participants did not feel comfortable being so closely connected to experimental technology and rated their experience differently from those who were more relaxed. This is also reflected in the higher standard deviation of part B of task 2.

Looking at the median values of the forehead in task 2, one will notice a very high ranking, together with the lowest rating. We believe this is due to the special role the forehead had in our setup. It allowed for very close coupling between visual and haptic cues; the remote user could see the hand reach out and then feel the touch. This effect made it feel like a very appropriate location for a touch point, while at the same time remaining a rather inappropriate place to touch somebody.

Table 1. Average rating of touch areas with standard deviation (Higher ratings indicates 'more appropriate' and lower indicates 'less appropriate')

	Task 1 (physical touch)				Task 2 (mediated touch)			
	A (rank)		B (evaluation)		A (rank)		B (evaluation)	
	mean	stdv	mean	stdv	mean	stdv	mean	stdv
Lower Back	**4,5**	1,5	**1,6**	1,8	**5,0**	2,1	**4,1**	2,8
Higher Back	**2,7**	1,0	**4,6**	1,1	**3,2**	1,4	**2,9**	2,1
Thigh	**7,1**	1,5	**4,3**	1,8	**6,9**	1,5	**4,8**	2,6
Belly	**6,3**	1,1	**3,5**	2,0	**6,4**	1,4	**4,6**	2,6
Chest	**5,6**	1,8	**1,4**	2,0	**4,8**	1,5	**4,1**	2,9
Shoulder	**1,4**	0,6	**2,2**	1,0	**2,1**	1,5	**2,2**	1,8
Hand	**3,3**	1,9	**3,8**	1,6	**2,9**	1,7	**2,5**	2,0
Forehead	**5,1**	1,8	**4,2**	2,2	**4,5**	2,3	**3,8**	2,5
	Total		25,6		Total		29,0	

For sake of completeness, we report both average and median values, though we believe the median to be a better representation of our observations. We believe that the social meaning of touch was preserved. At the same time, idiosyncrasies of the system introduced new social meanings (i.e. touching the forehead had a different social meaning in the mediated condition than it has in non-mediated settings). We do not believe that all of the emotional impact of touch was mediated; though in a situation where visual, audible, and haptic cues are all accessible, an experience very close to that of touch could be achieved.

Table 2. Mode ratings of touch-areas (Higher ratings indicates 'more appropriate' and lower indicates 'less appropriate')

	Task 1 (physical touch)		Task 2 (mediated touch)		Task2 – Task1 (difference between tasks)	
	A (rank) mode	B (evaluation) mode	A (rank) mode	B (evaluation) mode	A (rank) difference of modes	B (evaluation) difference of modes
Lower Back	6	3	2	2	-4	-1
Higher Back	3	1	3	1	0	0
Thigh	8	7	8	4	0	-3
Belly	7	3	7	2	0	-1
Chest	5	4	5	2	0	-2
Shoulder	1	1	1	1	0	0
Hand	2	1	2	1	0	0
Forehead	6	2	7	1	1	-1
Sum of evaluations		**22**		**14**		**-8**

Table 3. Questionnaire results, remote participants (on a scale of 1 to 5, where 1 indicates 'strongly disagree' and 5 indicates 'strongly agree')

	Remote Task 2				Remote Task 3		
	Mean	STDV	Median		Mean	STDV	Median
The haptic cues were easy to notice	3,91	0,96	**5**		4,09	0,76	**5**
The haptic cues were a valuable addition to the audio and video	3,79	0,94	**3,5**		4,12	0,76	**4**
The local person interacted with my body	2,82	0,83	**2,5**		3,71	0,97	**4**
My body was touched	2,12	1,04	**1,5**		-	-	**-**
The system helped understand the other persons body	2,5	1,51	**1**		3,56	0,98	**4**
The system could convey a feeling of closeness	3,26	1,15	**4**		3,59	1,19	**4**
I felt an emotional reaction when the local person was in close proximity	-	-	**-**		3,82	1,29	**5**
I preferred the proximity sensor over the touch sensor	-	-	**-**		3,32	0,92	**3**
The mediation was hermeneutic	3,69	0,61	**3,25**		3,07	0,43	**2,75**
The mediation was embodied	2,31	0,61	**2,75**		2,93	0,43	**3,25**

Results (Task 2 & Task 3)

Remote participant responded to a 5 point Likert questionnaire. The results presented in table 1 are accumulated from two questions each, one phrased negatively and the other positively. The last two questions concerning embodied and hermeneutic relations are accumulated from a total of 8 questions, inquiring about the remote participants' experience of the interaction. Task 2 refers to the mediated experience using touch sensors, task 3 refers to the mediated experience using proximity sensors. We conducted a Wilcoxon Signed Ranks Test comparing touch sensors and proximity sensors on two aspects: "The mediation was hermeneutic" and "The mediation was embodied". We found that there was a significant difference for both the hermeneutic ($Z = -2.907$, $p < 0.05$) and embodied scale ($Z = -2.907$, $p < 0.05$) when comparing task 2 and task 3. Breakdowns of individual factors can be found in table 3.

The touch sensors were not able to give the remote participants a feeling of actually being touched, however, participants still felt that the touch system was useful. Participants reported that the proximity sensor gave them a better understanding of the other person's body, as well as a stronger feeling that the other person was actually interacting with their own body. Also, the proximity condition was able to evoke a deeper sense of embodied mediation than the touch sensors. The participants, however, did not significantly prefer either version of the system over the other.

Based on our observations of task 2, we believe that the visual and kinetic aspects of the system created embodied experiences. This became evident as many users had trouble reporting on them,
presumably because their attention was focused *through* the technology rather than at the technology. The haptic elements of the system, on the other hand, required a great deal of interpretation. Users felt they had to make a conceptual leap between a vibration cue and the feeling of touch, thus reducing the vibration cues to symbols. Therefore, the haptic mediation can primarily be considered hermeneutic. As the hermeneutic and the embodied elements contributed to the experience, the experience we designed must be considered as a combination of various layers of hermeneutic and embodied mediation.

Of special interest to us was why task 3 appeared to enable a better sense of embodiment. We have no conclusive answer, but there are several factors that we believe to have played a significant role. The proximity / vibration coupling was simply easier to make sense of. The vibration corresponded directly to the position of the local user, which was simultaneously visible to the remote user. The coupling between close and far away was easier to understand and anticipate than the touches. We believe the simplicity of the process by which the interaction becomes meaningful is a reason why task 3 was perceived as more embodied.

Another factor that may play a role is that in task 3 we are creating something new, rather than emulating something which already exists. In order for the remote user, during task 2, to accept the vibrations as touch, the remote user needs to forget or ignore what touch actually feels like, and instead mentally create a new definition of the sensation. We believe that this creates a larger mental load than simply responding to a completely new sensory sensation as is done in task 3. This additional mental step would shift the experience away from an embodied experience and towards a hermeneutic experience.

Conclusion

In this study we presented a telerobotics system which was designed to create an experience of remote presence. We evaluated this system, by comparing different methods of mediated touch to non-mediated touch. In order to compare these experiences in a meaningful way, we drew on a vocabulary introduced by Ihde (1990), noting both where hermeneutic or embodied relations occurred. Our study provides support that intentional and designed mediation of abstract concepts, such as presence or social meaning, are indeed possible.

Based on the comparison of non-mediated (task 1) and mediated touch (task 2), we believe that social meaning and the emotional significance of touch is preserved in our system. Based on the comparison of two different implementations of mediated touch (task 2 and task 3) we believe that in order to design an embodied system, one need not strive towards complete mediation of all possible sensations. Also a clear mapping between input and output that is easy to understand and to anticipate, as is present in task 3, seems to be more effective than a crude emulation of touch, as implemented in task 2. Finally, we believe that users find it easier to establish an embodiment relation with novel sensations, than with sensations they are already familiar with.

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