Embodied Tele-Presence System (ETS): Designing Tele-Presence for Video Teleconferencing

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Abstract. In spite of the progress made in tele conferencing over the last decades, however, it is still far from a resolved issue. In this work, we present an intuitive video teleconferencing system, namely - Embodied Tele-Presence System (ETS) which is based on embodied interaction concept. This work proposes the results of a user study considering the hypothesis: " *Embodied interaction* based video conferencing system performs better than the standard video conferencing system in representing nonverbal behaviors, thus creating a 'feeling of presence' of a remote person among his/her local collaborators". Our ETS integrates standard audio-video conferencing with mechanical embodiment of head gestures of a remote person (as nonverbal behavior) to enhance the level of interaction. To highlight the technical challenges and design principles behind such tele-presence systems, we have also performed a system evaluation which shows the accuracy and efficiency of our ETS design. The paper further provides an overview of our case study and an analysis of our user evaluation. The user study shows that the proposed embodied interaction approach in video teleconferencing increases 'in-meeting interaction' and enhance a 'feeling of presence' among remote participant and his collaborators.

Keywords: Embodied Interaction, Multimodal Interaction, HCI, Audio-Video Conferencing, Head Gesture, Tele-Presence.

1 Introduction

The massive increase in computational power and the expanding context in which we put that power to use - both suggest that we need new ways of interaction with computers. These intuitive ways should be better tuned to our needs and abilities and should be better than tangible and social interaction approaches of last century. One of the well known approaches is 'Embodied Interaction' approach. Paul Dourish, in [1], pointed out that computing is moving into the social and the physical spaces and research in embodied cognitive science emphasized that a close interaction of brain, body and environment is central to the emergence of cognitive processes [2]. In our research work, the theories

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of tangible, social and embodied interaction, together with cognitive science are used to design a novel video conferencing system.

To collaborate and perform social activities across geographical distances, researchers have been developing infrastructures and technologies such as cell phones and internet based video teleconference systems (VTCSs) [3]. In general, VTCSs have advantage over audio teleconferencing as they facilitate users with better understanding and enhance verbal description based on facial expressions. However, todate these VTCSs are abortive in presenting nonverbal behaviors as humans express in face to face communication[4]. In this work, we have explored an intuitive way to control and interact with VTCS inspired by the Embodied Interaction concept which emphasizes on "the creation, manipulation and sharing of meaning through *engaged interaction* with artifacts"[1] (p. 126). Now the question is how to design an effective video teleconference collaboration and presence experience, which can express, pursue and share social skills and un/intentional behaviors of a remote user?

To study new couplings between intentional behavior and interaction for shared meanings, we have designed a system which expresses a remote person's facial expression, focus of attention and head gestures with other person(s) (or collaborators) sitting in a meeting room, namely - Embodied Telepresence System (ETS). Drawing on embodied cognition insights, we attempt bring mind (disembodied brain) and body (embodiment) closer to introduce new way of video conferencing which is different from the standard audio-video conferencing systems. ETS integrates audio, video and mechanical embodiment of head gestures. Considering the proposed approach, we study the perceived 'feeling of presence' among local collaborators. According to our best knowledge there is no VTCS (based on the embodiment concept) available to study such intentional head movements for shared meanings in remote presence.

2 Related Work

The physical limitation of presence i.e. one person cannot be present in two places at the same time has been overturned by telepresence systems. The concept of teleconferencing was given by AT & T through its picture phone device which was the birth of teleconferencing [5]. Since then new tools and approaches have been proposed to delve deep into human experience and to articulate new video teleconference collaboration methods. Hydra was an attempt to swerve from standard video conferencing with its four-way video conferencing system [6]. Over the years, researchers have been comparing VTCSs with face to face interaction and have figured out many issues like eye contact, turn-taking [7], gaze direction estimation [8], side conversation, emotions, nonverbal behaviors [4] and different environment spaces [9]. A number of software and hardware solutions have been proposed to solve above mentioned problems. For example, Personal Roving Presences (PRoPs) [10] and VGO provide tele presence in remote space by presenting video, audio, mobility and simple gestures. Furthermore, the demand of nonverbal behaviors in teleconferencing systems leads to development of various commercial VTCSs such as; Giraff, TiLR and Willow Garages Texai etc. MIT Media Lab's Mebot [11] robot is aimed to give person a richer way of interaction with an audience as compared to standard audio-video conferencing. Microsoft has also presented Embodied Social Proxy (ESP) [12] and concluded that people using ESP in their daily work find an improvement in interpersonal connection (for comprehensive overview on VTCSs, see [13]). More generally, researchers have explored a range of technological intermediations that might facilitate nonverbal behaviours to achieve collaboration as close as possible to face to face interaction. Human interactions in real-world are always mediated through living bodies [1] and all the above mentioned research provides that kinetic VTCSs give better feeling of presence of remote person. While there are multiple researches on using the kinesthetic sense which is vital to awareness design [14]. However, according to [15], it is required that a reexamination of existing approaches to *system design* should be done where many other factors have been prioritized. Considering this fact, researchers have reported following important issues with current VTCSs[13]:

- No proper gesture representation,
- Not all/partial degrees of gesture orientations are studied,
- Unable to fully create/present a 'feeling of presence' study,
- No Adaptability issues are considered.

This study aims to fill these gaps in this field of research. We seek to find the answers in embodied interaction approach by excluding mobility and only considering a remote user's precise head movements for presenting head gestures to local collaborators.

3 Embodied Telepresence System (ETS) - A Proof OS Concept

To test our hypothesis that " *Embodied interaction* based video conferencing system performs better than the standard video conferencing system in representing nonverbal behaviors, thus creating a 'feeling of presence' of a remote person among his/her local collaborators", we have designed an Embodied tele-presence System (ETS) which adds more perceptible head gestures in a standard video conferencing. ETS mechanical design consists of a stable platform for tablet PC or smart phone with three degrees of freedom. ETS software module consists of 1)face & head localization, 2) head pose estimation and broadcasting of mean face; which is installed on a remote person's PC.

3.1 Mechanical Design

ETS mechanical design has three degrees of freedom platform that actuate the tablet PC mounted on it using three servo motors attached in a configuration to give all three degrees of head orientation (yaw, pitch and roll). More specifically, one servo motor is attached to the base to give yaw movement and two servo motors are attached for either pitch or roll movement. The actual design and CAD model is shown in figure 1.

Fig. 1. Embodied Telepresence System (ETS) Actual Design and CAD Model

Mathematical Modelling of ETS Mechanical Design: Formally, if the angle of rotation of three motors are defined by $\Theta = \{\Theta_1, \Theta_2, \Theta_3\}$, where Θ_1 denotes angle of rotation for base servo motor and Θ_2 & Θ_3 denote angle of rotations for two servo motors on the top. Then the output angles for yaw, pitch and roll are denoted by α, β, and γ respectively. Then

$$[\alpha, \beta, \gamma] = f(\Theta_1, \Theta_2, \Theta_3) \tag{1}$$

This forward kinematic model is solved by Denavit-Hartenberg (DH) convention [16]. The position and orientation of the end effector in the inertial frame are given by;

$$H = A^1(\Theta_1) \times A^2(\Theta_2) \times A^3(\Theta_3) \tag{2}$$

Where A^i is homogeneous transformation and is represented by a product of four basic transformations by equation 3, where a, d, Θ, α are unique numbers.

$$A^i = Rot(z, \Theta_i) \times Trans(z, d) \times Trans(x, a) \times Rot(x, \alpha) \tag{3}$$

The final homogeneous transformation matrix is given by 3×3 rotation matrix R, and 3×1 translation matrix t.

$$H = \begin{pmatrix} R & t \\ 0 & 1 \end{pmatrix} \tag{4}$$

We can calculate the yaw, pitch and roll values from rotation matrix.

$$H = \begin{pmatrix} r_{11} & r_{13} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \tag{5}$$

where

$$\begin{aligned} Yaw &= \tan^{-1}(-r_{31}/ \sqrt{r_{32}^2 + r_{33}^2}) \\ Pitch &= \tan^{-1}(r_{32}/r_{33}) \\ Roll &= \tan^{-1}(r_{21}/r_{11}) \end{aligned}$$

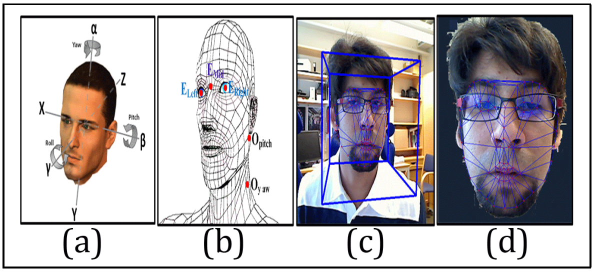

Fig. 2. [From left to right] ETS Software Module (a)-Human head rotation axis Yaw, Pitch and Roll (α, β and γ). (b)-Pivot points at cervical vertebrae to calculate yaw and pitch movement respectively. (c-d)- Constraint Local Model (CLM) of human face and Mean Face Extraction from CLM.

3.2 ETS Software Module

The software module has employed computer vision and machine learning methods for remote user's head pose estimation, mean face extraction and broadcasting. For head pose estimation we used a simple geometric method based on a monocular camera by exploiting eyes region relationship with face area [17]. The proposed geometric method employs anthropometric knowledge of human face to model the head motion as a rigid body movement(see Figure 2) (see [17] for more details).

It is vital to remove the in-frame head movement for ETS functionality for that we have extracted and broadcasted mean (remote person) face instead of rendering complete video frame. For this purpose we have employed a Constrained Local Model (CLM) [18]. CLM models an unseen image in an iterative manner by generating templates using the joint distribution model (both appearance and shape model) and the current parameter estimates (see [18] for more details). We have applied CLM on the face of a remote person to extract the mean face. In our extended CLM model the remote person's face is extracted from the image as shown in Figure 2-c,d. The purpose of extracting mean face is to remove the in-frame head movement from the presented contexts and transmit this mean face with the facial deformation (like eyebrow movement, lips movement, eyes movement) to local collaborators. These steps are required for the fully functional system:

1. Estimate the pose and the mean face of the remote participant.
2. Establish the audio-video communication and data communication between the remote participant and his collaborators.
3. Send the estimated yaw, pitch and roll angles of remote participant's head to ETS (at collaborators end) over a wireless channel.
4. Wireless module at collaborators end receives yaw, pitch & roll angles and passes it to ETS controller for further processing.
5. ETS controller then controls three servo motors accordingly to get the required yaw, pitch and roll orientation of ETS.

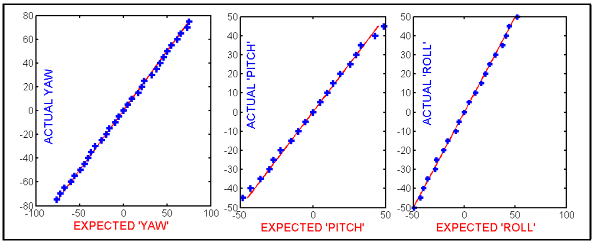

Fig. 3. Expected Rotational angles Vs Actual Rotational angles for (a) Yaw (b) Pitch (c) Roll

3.3 ETS System Level Evaluation

We have evaluated the functionality of ETS using two parameters: namely; *Accuracy*- with respect to pose angles, and *Efficiency* with respect to time. Accuracy of the system is measured by comparing the remote user's head pose values (i.e. expected pose angles) with pose values of the mechanical platform (i.e. actual pose angles). The required results of yaw, pitch and roll angles are shown in Figure 3(a, b, c). These results show that the average error is 0.183, 1.75 and 0.567 (degrees) in yaw, pitch and roll angles respectively. The efficiency of the system is about how much time is required in order to accomplish one cycle of full task. The algorithm for pose estimation and mean face extraction processes at 20 Hz. So, after every 50ms a wireless command is transmitted from remote participant end to mechanical platform end. The process of receiving command, extracting yaw, pitch & roll values and generating PWMs for three servo motors takes 100ms. Hence, the overall efficiency of the system is 10 Hz.

4 Presence: Local Collaborators Perspective

In this work, we have conducted the study to measure the 'feeling of presence' of a remote user at a collaboration site using ETS. Here a remote user is a person who remotely connects to his/her collaborators via the ETS-software whereas the local collaborators are those who are situated at the same physical location as the ETS. Presence is generally defined as the subjective experience of being in one place or environment, even when one is physically situated in another place or environment [19]. It has many dimensions but two of the dimensions are relevant to VTCSs - namely, social and spatial presence . With respect to local collaborators, the adapted definitions of spatial and social presence are 1)Spatial presence: it occurs when local collaborators' perception fail to accurately acknowledge the role of the technology that makes it appear as if the remote person is in a local environment [20]. 2) Social presence: It emerges when local collaborators fail to acknowledge the role of the technology in the communication with the remote person [10].

To validate our hypothesis, we have investigated the strength of the ETS system on creating a sense of presence of a remote person among local collaborators in consideration with social and spatial dimensions of presence.

4.1 Feeling of Presence: Measures

According to [22], presence is a subjective sensation or mental manifestation that is not easily amenable to objective physiological definitions and measurements. Generally, one way of measuring the degree of subjective presence involves a psychophysical test e.g; the use of physiological measures such as skin conductance, blood pressure, heart rate, muscle tension, respiration, posture, ocular responses, and so on. Another possibility is the use of 'direct' or 'Class A' measures of presence [23]. It involves subjective, paper-and-pencil questionnaire items based on the dimensions of the presence under study and based on the different hypothesis set before performing the experiment. It is argued that these measures are comparable and reliable (see [23]). We have adapted 'Class A' measures for our study to analyze the perceived presence. We have selected five the most important and most relevant measures for each dimension of (spatial and social) presence in our study.

We have selected widely accepted five important measures for spatial presence [24,25]:

1. **Realness**: The degree to which a medium can produce a seemingly accurate representation of objects, events and people that look, sound, and/or feel like the "real" thing.
2. **Awareness**: A feeling of presence of a person in a same space.
3. **Focus of Attention**: A person can perceive the other person's focus of attention such as selective attention & gaze direction.
4. **Cooperation**: Cooperation means an active meeting in which collaborators require complete engagement and participation of each collaborator.
5. **Enjoyment**: A person enjoys the presence of the other person.

The selected five relevant measures for social presence are:

1. **Co-presence**: The degree to which the observer believes s/he is not alone and secluded.
2. **Psychological involvement**: The degree to which the observer allocates focal attention to the other, empathically senses or responds to the emotional states of the other.
3. **Behavioral engagement**: The degree to which the observer believes his/her actions are interdependent, connected to, or responsive to the other.
4. **Mental immersion**: Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment.
5. **Active/Passive interpersonal**: Interpersonal focuses on the bond between two people.

5 User Study

5.1 Participants and Procedure

Twenty able-bodied subjects (10 males and 10 females) from five different countries (Sweden, England, Pakistan, Iran and China), ranging in the age from 18 to 40 (with an average age of 24.05) have participated in our experiment. The English language was chosen as a means of communication for this experiment and all participant were fluent in English. All participants were provided with a 5 minutes training session, where they were shown the ETS and briefly informed about the purpose of the experiment. They were also shown how their head movements were mapped to the ETS and how to move head mounted display left or right while addressing to any specific local collaborator. At the end of the training session, all the participants were shown the local and the remote site.

We have selected 5 participants at a time, one from each country. One person was chosen as a remote user and other four were his/her local collaborators. The experiment was performed in two sessions; one with normal commercial VOIP based software (i.e., Skype) and other with ETS. During the experiment, the remote user (from one specific country) was asked to talk about his/her country and his/her local collaborators (from other 4 countries) were told to ask questions related to their interest.

Upon completion of the experiment, the participants were asked to fill in the questionnaires. These questions were adapted according to our experiment and they were asked in English. Moreover, there were total of 30 questions in a questionnaire; 15 questions for measuring social presence and 15 questions for measuring spatial presence. Thus, for each dependent measure we have asked 3 questions. Furthermore, for all the questions a 7-points likert scale is used where 1 = Not at all and 7 = to a very high degree.

6 Results and Discussion

The questionnaire results were analyzed using ANOVA analysis as well as means and standard deviations for all dependent variables. The results of the perceived social and spatial presence after experiencing standard video conferencing (Skype) and Embodied Tele-presence System (ETS) are shown in Table 1 and Table 2.

An overall concerns of this user study was to analyze ‘whether the novelty of using precise head gestures potentially increases the level of presence among local collaborators’. Furthermore, it is clear from the results that the collaborators gave their preference to ETS on all dependent measures. Participants gave ‘Realness’ and ‘Awareness’ mean-score of 5.54 and 5.50 respectively (see Table 1); from this it is clear that the ETS is an acceptable representation of a remote user in a local environment. It was also observed that sometimes local collaborators fail to realize the role of technology when they use phrases like ‘hey’ to attract the ‘attention’ of the ETS. An important issue with standard VTCSs is that one cannot specify the remote person’s gaze direction or focus of attention.

Table 1. Means and standard deviations for spatial presence dependent measures (S for Skype, E for ETS, μ for mean and σ for std. dev.

Dep. Mea.	μ**(S)**	σ**(S)**	μ**(E)**	σ**(E)**
Realness	4.33	0.36	5.54	0.58
Awareness	3.5650	0.40	5.50	0.65
Focus of attention	3.21	0.35	5.95	0.39
Cooperation	3.73	0.36	5.23	0.42
Enjoyment	4.62	0.52	5.77	0.57

Table 2. Means and standard deviations for social presence dependent measures (S for skype, E for ETS, μ for mean and σ for std. dev.

Dep. Mea.	μ**(S)**	σ**(S)**	μ**(E)**	σ**(E)**
Co- presence	4.59	0.46	5.16	0.55
Psy. involvement	3.59	0.53	5.35	0.56
Behavioral engagement	3.33	0.56	5.71	0.46
Mental Immersion	3.57	0.57	5.09	0.54
Active/Passive interpersonal	4.22	0.55	5.19	0.62

However, with the turn taking capability of ETS the local collaborators could easily identify the 'focus of attention' of the remote user and thus it received a mean-score of 5.945, which was the highest among all. It is also evident from the results that cooperation is realized with head moving capability of ETS (mean-score = 5.23). All participants gave a good score to 'enjoyment' which shows that they have enjoyed the whole experience of interacting with ETS as compared to VOIP based software.

The measures for social presence were also of particular interest with respect to local collaborators perspective and the results indicate that the ETS creates a feeling of co-presence in a meeting room and gives better understanding, clarity and psychological involvement by its verbal and nonverbal communication. When a remote user turns ETS to address one local collaborator then that local collaborator felt behaviorally engaged with the remote user. This was confirmed from questionnaire results; i.e., 5.71 mean-score for 'Behavioral Engagement'. However, 'Mental Immersion' got a mean score of 5.08 for ETS which is greater than 3.56 for Skype. In our experiment, we have invited participants from different countries and getting a mean score of 5.195 for 'Active/Passive interpersonal' which is considered to be a very good result.

Table 3. Effects of User's Mental Immersion

Source	**F**	**P-value**
Behavioral Engagement	8.052	0.035
Co-presence	7.56	0.032

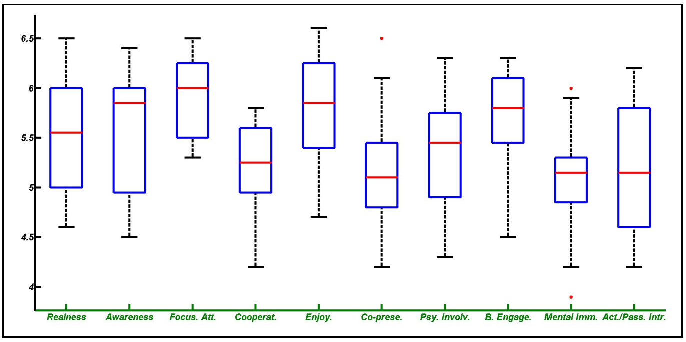

Fig. 4. Mean Questionnaire score for combined spatial and social presence

We have also performed ANOVA analysis and found that user's 'enjoyment' has a significant effect on 'Awareness', with F = 8,56 and P value = 0,020. There was also a significant effect of 'Mental Immersion' on 'Behavioral engagement' and 'Co-presence', as shown in Table 3. From Figure 4, it can be seen that the mean values of all 10 dependent variables for measuring social and spatial presence vary from 5.08 to 5.95. This small range of mean values shows that these dependent variables are interrelated and are good representation of social and spatial presence.

Based on our user studies we have found some issues in our current ETS mechanical design. This study shows that despite achieving 'focus of attention' of a remote person, the embodied tele-presence system can not achieve true eye contact with the local collaborator; which was anticipated. Furthermore, we have also discovered some tradeoffs between one-to-one interaction and social presences as swivelling (more than 90 degrees) the ETS toward one specific collaborator might exclude other collaborators, which can result in a decrease of social presence of the remote person with rest of the group. During experiments, some participants also mentioned about the small delay in the mechanical system which is distracting. These hardware and software related issues will be considered in the future prototype.

7 Concluding Remarks

In this work we have presented a novel design for video teleconferencing - namely Embodied Telepresence System (ETS); that incorporates an embodied approach by considering the remote user's precise head movements for presenting head gestures to collaborators. In addition to audio-video conferencing, ETS has the capability to mimic human head rotation and express nonverbal cues that people use in face to face interaction. Our system comprises of all three degrees of head orientation and according to the system evaluation, ETS can express head gestures accurately and efficiently with maximum error of 1.75 degree and minimum speed of 10 Hz. ETS is a combination of disembodied mind with body and to prove this concept a user study was conducted to see whether this concept improves the feeling of presence of a remote user among his collaborators. The findings of this project are positive and ,if carefully implemented, embodied interaction in video teleconferencing can lead to much better results than traditional audio-video conferencing. We conclude that based on our results from our pilot study that these nonverbal head gestures enhance the feeling of spatial and social presence of a remote person, considering all their dependent variables. The hypothesis, ' *Embodied interaction* based video conferencing system performs better than the standard video conferencing system in representing nonverbal behaviors, thus creating a 'feeling of presence' of a remote person among his/her local collaborators' suggestively upheld on the basis of the results deduced from the user study. We conclude that ETS with precise head gesture mapping has the potential to solve problems, such as 'lack of presence' and 'expression of engagement'. We see further research role in adapting embodied interactions in VTCS's design, and we particularly see the need to further develop both mechanical and theoretical frameworks to implement the 'presence' nature of the VTCS interfaces.

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