Asymmetries in Collaborative Wearable Interfaces

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Abstract

Communication asymmetries are inherent in collaborative dialogues between wearable computer and desktop users. This paper gives a definition and overview of what communication asymmetries are and their potential impact on the design of collaborative wearable interfaces. We also review results from collaborations with two asymmetric interfaces and present a set of implications for developers of collaborative wearable interfaces.

1. Introduction

Wearable computers provide new opportunities for communication and collaboration, particularly in mobile applications. Several applications using wearable computers have already demonstrated the benefit of collaborative wearable interfaces. For example, Siegel et al. [11] found that the presence of a remote expert collaborating with a wearable user enabled subjects to work more effectively than working alone. Similarly, Kraut et. al. [7] examined subjects performing a bicycle repair task with a wearable display, head mounted camera and wireless link to a computer with a help manual. They found that subjects completed repairs twice as fast and with fewer errors with the assistance of a remote expert compared to using the help manual alone. Garner et. al. [3] and Steve Mann [9], among others, have developed similar examples of collaborative wearable systems that use shared video, audio and text.

In all these settings, the collaboration has been between a pair of participants, one with a wearable computer, the other at a desktop workstation. Indeed, one of the natural applications for wearable computers is to provide just in time assistance between a deskbound expert and a mobile fieldworker with wearable computer. However, collaboration in this setting is very different from engaging in traditional video conferencing; the use of disparate technology by each participant results in the introduction of asymmetries in the communication. For example, in Kraut's task the user with the wearable display broadcast images of the task space back to the remote expert, while the remote expert sent back either video of their face or no video at all.

Although there has been considerable study of mediated communication outside of the field of wearable computing, this has generally been with the tacit assumption that all the participants are using the same interface. This is often not the case in collaboration between desktop and wearable computer users. In this paper we elaborate on the concept of asymmetries in collaborative interfaces and present preliminary results from several pilot studies. We are initially focussed on collaboration between two geographically remote users, one with a wearable computer, one with a desktop. However the concepts presented in the paper should be more widely applicable.

2. Communication Asymmetries

We define communication asymmetries as an imbalance in communication introduced by the interface used for communication, the expertise or roles of the people communicating, or the task undertaken.

Using this broad definition it is obvious that there are many possible types of communication asymmetries in collaborative wearable applications. In order to more fully understand the possibilities that could arise we present a simple example of a typical collaborative wearable system. Figure 1 shows a schematic of a wearable user with a head mounted display, microphone and camera collaborating with a desktop user with a monitor, microphone and camera.

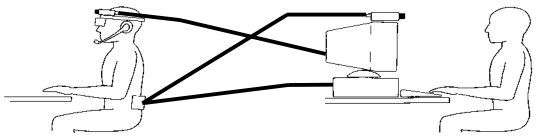

Fig 1. Wearable and desktop collaboration

If both users have the same ability to share audio, video and desktop applications then (using Bauer's definition [1]) there is symmetry in collaborative functions they can perform, i.e. *functional symmetry*. However one or more capabilities could be removed from either user to introduce *functional asymmetries*; the wearable user may be able to send video/images, but the desktop user may not have a camera to send images back. Similarly, even though the users may have the same functional capabilities they may have different physical interface properties; the resolution of the head-mounted display may be different from the desktop users monitor. We call this an *implementation asymmetry*.

If both users converse using only audio then they can share the same conversational cues. We call this *social symmetry*. However if the desktop user sends video of his face, while the wearable user sends video of the real world only one person can respond to facial non-verbal signals so *social asymmetries* are introduced.

If both users are trying to collaborate on the same task (such as collaborative sketching), and they have an equal role as collaborators and have access to the same information, then there are *task* and *information symmetries.* However if the wearable user is trying to complete a real world task and the desktop user trying to help then *task asymmetries* are introduced. The wearable user is trying to focus on the real world, while the desktop user is trying to build a mental model of the real world using the sensor data provided by the wearable user's computer. Similarly if the desktop user is an expert providing remote technical assistance to the novice wearable user, *information asymmetries* occur.

We believe that because of the disparate hardware used it is impossible to design interfaces for collaboration between a desktop and wearable computer without introducing communication asymmetries. However, by understanding these asymmetries then any damaging effect they may have on communication can be minimized.

3. Background

The majority of previous teleconferencing research has assumed that users have access to the same conferencing hardware, implying functional and implementation symmetries. Even in this case the technology introduces communicative asymmetries. Gaver discusses the affordances of media spaces describing among other things how video conferencing systems restrict peripheral vision [4]. As Heath and Luff point out, the lack of peripheral vision causes certain actions to lose their communicative impact when performed through video [5]. Thus looks, glances and gestures pass unnoticed by their intended recipients. Similar effects are seen in immersive virtual environments [6]. These effects cause Sellen to conclude that mediated collaboration will always be different from face to face collaboration [10].

Given this conclusion we can also explore how wearable systems introduce further asymmetries. In Kuzuoka's Shared View project [8] a remote instructor taught a technician how to operate a numerically controlled milling machine. The student wore a head-mounted camera and display that was used to overlay the instructor's gestures over video of what the student was seeing. They found that collaboration was most effective when instructor and student could share a common viewpoint and both the instructor and student could use gestures with speech, suggesting that functionally symmetric interfaces improve collaboration.

However, in the bicycle repair project of Kraut et. al. [7], they found there was no performance difference between the condition where both participants could use audio to communicate, or the functionally asymmetric condition where only the remote expert could use audio. They also found that varying the visual and auditory affordances did affect communication measures, such as how proactive the expert was in giving help. In both this case and Kuzuoka's the expert has more information and expertise available than the technicians with the wearable interface.

The experiments of Steed et. al. [12] compared collaboration between three subjects in a multi-user virtual environment and face to face meeting. In the virtual environment only one of these users were immersed using a head mounted display, while the others used a desktop interface, but they all had the same capability to navigate and interact with the virtual environment. They found that the immersed subject tended to emerge as leader in the virtual group, but the same person wasn't necessarily the leader in the face to face meeting. Thus, the implementation asymmetry may have effected the roles played out by group members in that experiment.

These results suggest that asymmetries can be introduced even when the physical interfaces and the roles of the collaborators are the same. In some cases these asymmetries may affect the nature of collaboration and task performance, while in others they have little effect. Obviously more research is needed to gain an understanding of the effect of communication asymmetries inherent in wearable interfaces. In the next section we present results from two pilot studies examining the effects of common asymmetries in collaborative wearable systems.

4. Preliminary Pilot Studies

In our research we have developed a number of interfaces that explore two types of collaboration:

- A wearable and desktop user collaborating on the same task with access to the same information.
- A wearable user engaged in a real world task getting help from a remote desktop expert.

In the first case, both users have equal roles and access to the same information. Thus the information flowing between the users should be symmetric and both interfaces should maximize data display and ease of collaboration.

In the second case the users are effectively engaged in two separate tasks; the wearable user in the real world task, the remote expert in creating a mental model of the real world task and providing effective assistance. The wearable user is largely responsible for data collection and sensing while the remote expert is responsible for providing expertise and higher level knowledge. Thus information flows between the users are different and there are different minimum interface requirements. The remote expert's interface should maximize the amount of data displayed from the wearable, while the wearable interface should maximize the ease of collaboration.

Considering this we have two hypotheses:

- When both the wearable and desktop users have the same task requirements and information access, then asymmetries may hurt collaboration.
- A wearable user will be able to collaborate effectively with a remote expert provided the functional, and implementation asymmetries match the task and information asymmetries.

In the remainder of this section we describe two pilot studies which explore these hypotheses further.

4.1. Asymmetric Mismatch

In this first experiment we introduced a number of asymmetries into a collaborative interface and examined the effect on user behavior. This was accomplished by comparing asymmetric conferencing between an augmented reality (AR) and desktop interface, with more traditional symmetric audio and video conferencing.

Augmented Reality Interface

The user with the AR interface wears a pair of the Virtual i-O iglasses head mounted display (HMD) and a small color camera. The iglasses are full color, see-through and have a resolution of 263x234 pixels. The camera output is connected to an SGI O2 computer and the video out of the SGI connected back into the HMD. The O2 is used for image processing of video from the camera and generating virtual images at 10-15 fps.

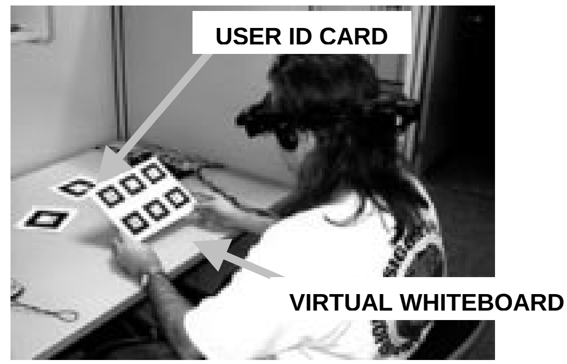

Fig 2. Using the AR Interface

They also have a set of small marked user ID cards, one for each remote collaborator with their name written on it (figure 2). To initiate communication, the user looks at the card representing the remote collaborator. Computer vision techniques are then used to identify specific users (using the user name on the card) and display a life-sized video view or a 3D virtual avatar of the remote user. Vision techniques are used to calculate head position and orientation relative to the cards so the virtual images are precisely registered [9] (figure 3).

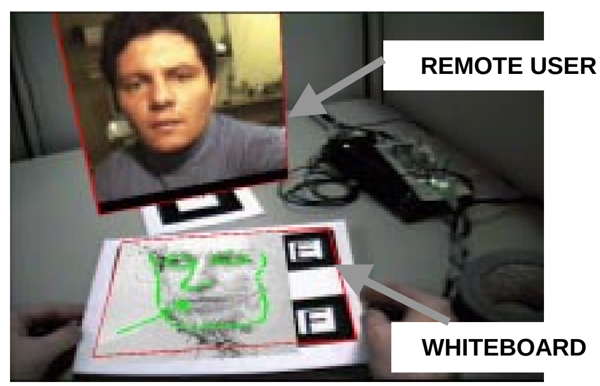

Fig 3. Remote user in the AR interface.

They also have a virtual shared whiteboard (figure 3), shown on a larger card with six registration markings. Virtual annotations written by remote participants and 2D images are displayed on it, exactly aligned with the plane of the physical card. Users can pick up the card for a closer look at the images, and can position it freely within their real workspace.

Desktop Interface

The wearable user collaborates with a user at a desktop interface. This interface has a video window of the image that the desktop camera is sending, the remote video from the AR user's head mounted camera and a shared white board application (figure 4). The video view from the AR user's head mounted camera enables the desktop user to collaborate on real world tasks. Users can also talk to each other using VAT, a program which enables audio communication between remote machines.

The shared white board application consisted of small views of five pictures as well as a large view of the currently active picture (figure 4). Clicking with the left mouse button on a picture changed the active picture to that picture. In the AR interface the selected picture was shown on the virtual whiteboard. The currently active picture could be drawn on by holding down the left mouse button, while the right mouse button erased the user's annotations. Either user could change the pictures or make annotations.

Fig 4. Desktop User Interface

Asymmetry Experiment

We compared collaboration with the AR and desktop interfaces to more traditional audio and video conferencing in three conditions:

Audio Only (AO): Subjects were able to speak and hear each other using headphones and wireless microphones, and collaboratively view and annotate pictures on a simple desktop application (figure 4).

Video Conferencing (VC): In addition to the conditions above, a desktop video conferencing application was used to show live video of the remote collaborator.

Augmented Reality (AR): One of the subjects was using the AR interface described above. The other subject was using the desktop interface of figure 4. The desktop user could also see video from the AR user's head-mounted camera, giving them a remote view of the AR users desktop.

Referring to our original classification, in the audio and video conferencing conditions both users have the same interface and so have symmetric communication conditions. However, in the AR condition we introduce three clear types of asymmetry:

- *Functional Asymmetries:* The AR user can see a virtual video window of the desktop user's face, but the desktop user sees the AR user's workspace, not their face.
- *Implementation Asymmetries:* The AR user sees images on a HMD, while the desktop user sees them on a monitor.
- *Social Asymmetries:* The AR user can see and respond to their partners non-verbal facial and gestural cues, while the desktop user primarily relies on voice.

If our first hypothesis is valid then we should expect these asymmetries to affect collaboration.

Procedure

There were 12 pairs of subjects from 19 to 45 years old; six pairs of males, three of females and three mixed pairs. They did not know each other and were unfamiliar with the application and collaborative task. After each condition subjects were given a communication survey, and after all the conditions they were asked to fill out an overall ease of communication survey.

A within subjects design was used. Each of the subject pairs experienced all three conditions. Subjects were told that they were to act as art buyers for a large art gallery. For each of the conditions they had to decide together which three pictures out of a set of five that the gallery should buy and the reasons why. Each subject was also give a paper copy of the five pictures they were considering in each condition, enabling them to see a higher resolution version of the images.

Before the experiment began subjects received training on how to use the desktop interface and also spent a few minutes in each condition with a sample set of pictures. In the AR condition, both subjects tried the HMD and desktop interface for a few minutes so they could gain an understanding of what the other user was experiencing during the actual experiment. For each condition subjects were given 10 minutes to complete the task, although in some cases they finished ahead of time. The order of conditions and the images used in each condition were varied to reduce order effects.

Survey Results

We differentiated each subject of the pair according to whether they were at the desktop for all conditions (No-HMD), or if they wore the HMD in the AR condition (HMD). In general the survey scores given by the HMD and No-HMD subjects for each condition were very similar, but varied across condition.

Overall, subjects felt that the AR condition was more difficult to communicate in than the audio only (AO) and videoconferencing conditions (VC). Figure 5 shows a graph of average subject responses to the question on overall communication; *Rate each communication mode according to how much effort you felt it was to converse effectively (0=Very Hard, 14=Very Easy).*

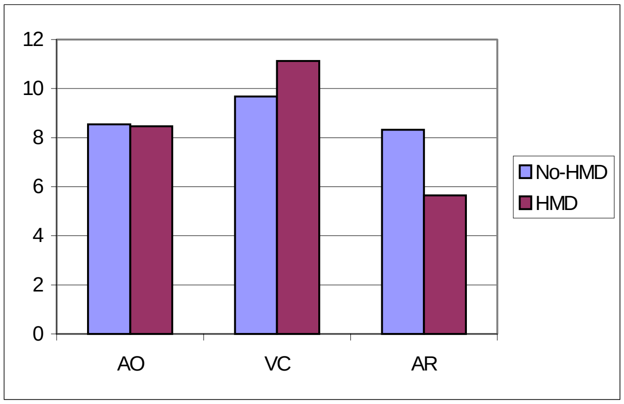

Fig 5: Communication Effort Across Conditions

Using a two factor (subject, condition) repeated measures ANOVA, we find a significant difference in scores between conditions ($F(2,47)=4.19$, $P<0.05$), but not between subjects ($F(1,47)=0.20$, $P=0.65$).

A similar result is found in the communication survey given at the end of every condition. Table 1 shows the average response to the statement *"I was very aware of the presence of my conversational partner" (0=Disagree, 14=Agree).* The AR condition is given a co-presence rating between that of the audio and video conferencing conditions. Using a two factor repeated measures ANOVA, we find a significant difference in scores between conditions ($F(2,47)=4.99$, $P<0.05$), but not between subjects ($F(1,47)=0.01$, $P=0.90$).

	AO	VC	AR
No-HMD	8.06	11.93	10.06
HMD	9.99	11.58	8.78

Table 1: Average Co-Presence Score

Subjects also felt that the visual cues provided by the AR condition were not as useful as the cues provided by the video conferencing condition for determining if their collaborator was busy. Table 2 shows the average scores in response to the question; *"I could readily tell when my partner was occupied and not looking at me"*. Using a two factor repeated measures ANOVA, we find a significant difference in scores between conditions ($F(2,47)=15.70$, $P<0.01$), but not between subjects ($F(1,47)=0.40$, $P=0.70$). Both the video and AR conditions were rated significantly higher than the audio.

	AO	VC	AR
No-HMD	3.18	11.56	6.13
HMD	2.27	9.04	8.29

Table 2: Average Awareness Scores

Finally, figure 6 shows the average response to the statement *"The mode of communication aided work"*. As can be seen the AR condition is again rated less helpful than both the audio and video conferencing conditions. A two factor repeated measures ANOVA finds a near significant difference in scores both between conditions ($F(2,47)=3.17$, $P=0.054$), but not between subjects ($F(1,47)=0.04$, $P=0.80$).

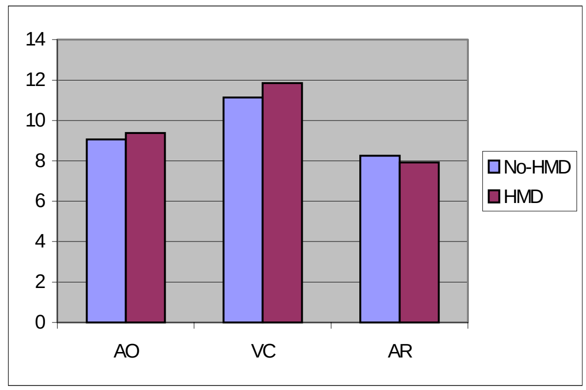

Figure 6: How Much Conditions Aided Work

Subject Comments

Several subjects commented on the asymmetries introduced by the AR interface. Most of these comments were about the functional asymmetry of the interface. Some desktop users found it disconcerting that the AR user could see them, but they couldn't see the AR user. They also felt uncomfortable seeing their own face in the task space video sent back by the AR user and said that set up an "unequal relationship". The virtual image of the remote person was also seen as distracting by some people, especially when it flickered in and out of sight due to the narrow field of view of the head mounted display.

Discussion

In this experiment subjects were given the same task and access to the same information. However in the AR condition functional, implementation and social asymmetries were present. As these results show these significantly impacted how well the subjects felt they could collaborate together, in some cases causing the subject to feel the AR condition was even less useful than audio alone. These results seem to support our theory that if the roles of the collaborators are the same then combinations of functional, implementation and social asymmetries may impede the collaboration.

4.2. Asymmetric Matching

The second study explored asymmetries in interfaces designed for collaboration between a desktop expert and wearable user. As previously discussed, this situation already introduces task and information asymmetries. However we hypothesized that if the functional and implementation asymmetries matched these asymmetries then collaboration would not be affected.

Experimental Task

The goal of the wearable user was to construct plastic models out of an Erector set with the help of a remote desk-bound expert. The wearable user wore a Virtual i-O head mounted display modified by removing one eyepiece to be monocular, and a small video camera. The remote expert used a desktop computer (an SGI O2) on which was shown the video from the head-mounted camera and a shared image browser application (figure 7). The shared image browser was developed using the TeamWave toolkit [13] and enabled images to be uploaded and drawn on. The expert could also annotate on the live video. Video output from the O2 was fed back into the head mounted display via a video switching box. This enabled the wearable user to switch between either views of the annotated camera image, or the image browser application. A full duplex audio connection between users was also provided.

Fig 7. Expert and Wearable User Collaborating

Using this interface we wanted to explore further the effect of asymmetries on collaboration by varying the video frame rates that each user saw. If our second hypothesis is correct then performing a task with varying video frame rates should more severely affect the remote expert who is focussing on the wearable users task space through the desktop interface than the wearable user who is focussing on the real world itself.

Procedure

The task was for the wearable user to build an Erector set model with expert guidance from the remote user under the following four video frame rates; 0 frames per second (FPS) (audio only communication), ¼ FPS, 1 FPS, and 30 FPS. For each of these four conditions the wearable user would initially begin building the model with no help and using incomplete instructions from the Erector set instruction booklet. After 5 minutes, communication with the remote expert would be allowed and then the expert would assist the wearable user for the next 10 minutes using the complete instruction book. This was to simulate a real-world remote technical assistance call. The expert was able to aid the wearable user by annotating their video of the task space and by uploading images from the model instruction booklet into the shared image browser.

Eight pairs of subjects took part in the pilot study, 14 men and 2 women, aged 18 to 28. Each group went through each of the four frame rate conditions with four different Erector set models. The order or sequence of the three video-present conditions was randomized to minimize the effect of learning on our results. Before the experiment began they were trained on a separate model until they felt comfortable with erector set construction.

The outcome of the collaboration was measured by the completeness of the models (number of steps finished), and a questionnaire asking for opinions about how easy it was to collaborate in each condition and other interface aspects.

Performance

There was no significant difference in performance across conditions. Table 3 summarizes the number of steps completed on each model for each of the frame rates. Using a single factor ANOVA, we found no significant difference between the number of steps completed across frame rate conditions (Single Factor ANOVA, $F(3,20) = 2.50$, P value = 0.065).

	0 fps	1/4 fps	1 fps	30 fps
Steps	5.75	3.50	4.75	4.67

Table 3: Average Number of Steps Completed.

Subjective

The expert and wearable user had different subjective experiences with the collaborative interface. After each condition they were asked to rate the answers to a number of questions on a scale of 1 to 10, where 1 was Ineffective and 10 Very Effective. The first three questions on the user questionnaire were:

(Q1) *Did the interface enable you to effectively understand the wearable user situation/be understood by the expert?*

(Q2) *Did the interface enable you to effectively understand questions/ communicate questions?*

(Q3) *Did the interface provide an effective means to give/get guidance?*

A single factor ANOVA was used to compare between the average subject scores for each question. Table 4 shows the average answers for each of these questions across the different frame rates, the ANOVA F statistic (F(3,28) and resulting P significance value.

	0	¼	1	30	F stat.	P Value
Q1*	4.88	6.16	6.76	8.38	2.95	P<0.01
Q2*	4.17	5.67	6.25	8.38	8.05	P<0.01
Q3*	4.29	6.33	7.38	8.46	8.93	P<0.01

Table 4a: Average Expert Response

	0	¼	1	30	F stat.	P Value
Q1*	6.08	6.35	7.92	8.21	3.22	P<0.05
Q2*	6.50	5.75	7.29	8.0	3.49	P<0.05
Q3*	4.90	5.83	7.67	7.83	4.87	P<0.05

Table 4b: Average Wearable User Response

As can be seen from these tables all the responses are significantly different. Subjects felt that as the frame rate increased they could understand the situation better (Q1), communicate more effectively (Q3) and give and get guidance more effectively (Q2). In the wearable users case there was little difference between ranking on these questions between 1 and 30 fps, while the expert always ranked the 30 fps case much higher than the 1 fps case.

This difference is particularly noticeable in the answers to question 5; *What degree of co-presence did you feel with the expert/wearable user (1=None, 10=Very Present)?* Figure 8 shows the average scores for the expert and wearable user across the different frame rates. A single factor ANOVA gives a significant difference between the experts' co-present ratings (F(3,28) = 9.38, P< 0.05), but not for the wearable user (F(3,28) = 2.95, P = 0.35).

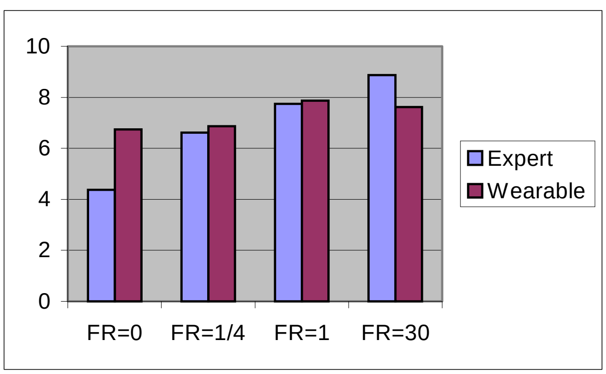

Fig 8. Subject ratings of Co-Presence (Q5).

Interface Components:

Subjects were also asked to rank how helpful the individual interface components were on a scale of 1 to 10 (1 = little help, 10 = very helpful). For the expert the interface components were audio (A), video of the task space (TS), shared graphics images (SG), the ability to annotate on the graphics images (AG), and the ability to annotate on the video image (AV). While the wearable user considered the following components; audio (A), the expert view of task space (EV), and the shared graphics image (SG). Table 3a shows the expert users' average ratings for each of the components, the ANOVA F statistic (F(3,28)) and the resulting P significance values. Table 5b shows the wearable users' component ratings.

	0	¼	1	30	F stat	P values
A	8.50	8.88	9.34	9.50	2.94	0.22
TS*	NA	4.38	7.38	8.63	8.38	< 0.01
SG	5.57	5.00	6.14	5.71	3.01	0.87
AG	4.71	4.00	5.14	6.00	3.01	0.44
AV*	NA	4.42	6.57	8.43	8.50	< 0.01

Table 5a: Expert Ratings of Interface

	0	¼	1	30	F stat	P values
A	9.00	8.75	9.00	9.25	2.95	0.88
EV	NA	7.13	8.13	8.38	3.47	0.25
SG	7.87	6.00	6.42	6.14	3.01	0.29

Table 5b: Wearable User Interface Ratings

As can be seen there are no significant differences between wearable user ratings for interface components across different frame rates. However the remote expert found the video of the task space and the ability to annotate on the video significantly more useful as the frame rate increased.

Both the wearable user and expert rated audio as the most helpful interface component. Using a two factor (frame rate, interface component) repeated measures ANOVA we can compare ratings for the different interface components. Doing this for the wearable user we find no significant difference between frame rates (F(2,63)=0.32, P = 0.74), but a highly significant difference in results between interface components (F(2,63)=21.64, P<0.001). Similarly, for the expert user we find a highly significant difference both between frame rates (F(2,90)=15.15, P <0.001), and between interface components (F(4,90)=16.69, P<0.001).

Discussion

These results agree with our second hypothesis. The wearable users felt they could collaborate equally well with 1 fps video as with 30 fps video, while the experts felt they needed high video frame rates for more effective collaboration. Similarly the experts rated the video view of the task space and the ability to draw on the video significantly more useful as the frame rate increased, while the wearable user thought the usefulness of the experts view didn't change as the frame rate increased. This implies that the expert and wearable user should be able to collaborate together effectively if there is the functional asymmetry of low frame rate video (1 fps) from the expert to the wearable user and high frame rate (30 fps) the other way. Thus if the functional asymmetries in the wearable interface match the task and information asymmetries collaboration may not necessarily be affected.

5. Conclusions

Computer mediated communication is fundamentally different from face to face communication and collaboration between a wearable computer user and a desktop user introduces a wide range of inherent asymmetries into the communication. In this paper we have described some of the possible asymmetries that may occur and presented results from pilot studies exploring various asymmetries.

Although our results are very tentative, it seems that the effect of communication asymmetries depends largely on the roles of the collaborators and nature of the task that they're engaged in. In the first study, when users both had equal roles, they felt that the differences between the interfaces impeded their ability to communicate, compared to traditional teleconferencing systems. In the second study, the asymmetries matched the differences in roles and so had less of an impact.

One implication from this is that designers of collaborative wearable interfaces need to match the interface capabilities to the roles of the users. For example, in supporting collaboration between a wearable user and remote desktop expert in a technical assistance role, half duplex high bandwidth video may be sufficient. Secondly, interface designers need to evaluate carefully the impact of providing additional communication cues. For example, in the first experiment adding visual communication cues in the AR condition did not improve performance over the audio only case. Finally, interface designers need to use a multifaceted approach to measure the impact of communication asymmetries. In our experiments, the interface differences affected measures of co-presence, awareness, communication effort and communication effectiveness.

In the future we plan to carry out more controlled studies to further characterize the effect of communication asymmetries. We will be particularly focussing on wearable interfaces that facilitate optimal collaboration between a worker in the field and a deskbound expert.

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