Communicative Functions of Haptic Feedback

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Abstract. In this paper a number of examples are presented of how haptic and auditory feedback can be used for deictic referencing in collaborative virtual environments. Haptic feedback supports getting a shared frame of reference of a common workspace when one person is not sighted and makes haptic deictic referencing possible during navigation and object exploration. Haptic guiding is a broader concept that implies that not only a single action, like a deictic reference, is made but that a whole sequence of temporally connected events are shared, sometimes including deictic referencing. In the examples presented in this paper haptic guiding is used by participants as a way to navigate while at the same time explore details of objects during joint problem solving. Guiding through haptic feedback is shown to substitute verbal navigational instructions to a considerable extent.

1 Introduction

The touch affordances (Gibson, 1966) that humans found of objects in their context over thousands of years of poking around in the nearby surroundings, together with the cooperative quality of human conversation (Clark and Wilkes-Gibbs, 1986), have most probably been important for human development. Being able to explore with your hands and communicate at the same time facilitate coordination of action and learning.

The question then arises; what communicative functions do haptic feedback in it self have? Here, haptic feedback refers to an integration of both kinaesthetic sensing and tactile sensing (Loomis and Lederman, 1986). First of all, a person can look at some one else using a tool or any object and imitate that movement and secondly they can hold on to the same object and through the joint action understand something about the other persons intentions and ways of doing a task. Gestures can show deictic reference (Clark, 2003; Clark, 1996) to i.e. an object, place or person, a skill (pantomimic gesture), specify manner of motion of an object (Fussell et al, 2004) and so on. Traditionally, gestures have been described as individually performed actions but what happens when people do a gesture together holding on to the same object or to a networked pointing device? Is that still gestures or something else, maybe it is guiding or guidance?

Furthermore, what is the reason why a teacher sometimes feels the urge to take the same tool that the student is using and show a movement by holding on to the same

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tool? Well, first of all the specific procedure can be taught. But something else is also communicated by the touch feedback that has to do with the force something is done with, and the exact direction in which it has to be done. These aspects are only possible or easier to convey by the touch modality compared to vision or hearing. This is also relevant for what researchers refer to as tacid or implicit knowledge. Apart from the above examples, there are other useful functions of haptic feedback for collaboration such as handing off objects, pulling in each end of something or jointly holding on to an object and do a manoeuvre that needs more than one person, such as folding a sheet. In this paper a number of concrete examples have been selected from two earlier studies that illustrate how the touch modality can be used in haptic interfaces in order for people to communicate and collaborate. This paper is theoretical in that it discusses different conceptual phenomena related to communicative aspects of haptic and auditory feedback, based on examples from the two studies that are presented and discussed. A report of the quantitative results and all the details of the methodology regarding the two studies are not presented in this paper. It is also worth noting that the general findings reported here is the result of an inductive analysis that specifically focus on communicative aspects of haptic and auditory feedback.

2 Background

Communication has been defined in many ways that are more or less restricting. The following definition by Cherry (1957) is useful for the kind of communication considered in this article: "*the psychological signals whereby one individual can influence the behaviour of another*". This definition opens up for investigating communication in a broad sense that also includes communication that is not verbal which many other definitions require. Research about gestures points out that gesturing in itself can be communicative (Clark, 1996) and that signals are the act of creating meaningful signs to others (Clark, 2003). For deaf people this is obvious and for blind and deaf people one useful communication option is sign language conveyed by haptic feedback. Gibson (1979) argued that humans not only perceive the affordances of objects but that also the social behaviour of other beings have affordances. Humans are dynamic and convey complex patterns of behaviour that other humans interpret as affording certain behaviours reciprocally in a continuous fashion. Humans interact with one another and behaviour affords behaviour. Gibson (1979) argued that:

"The perceiving of these mutual affordances is enormously complex, but nonetheless lawful, and it is based on the pickup of the information in touch, sound, odour, taste and ambient light"

Following this line of reasoning, multimodal input of information is important for an accurate understanding of another person's social affordances. Deictic references are important for common ground, that is defined as a state of mutual understanding among conversational participants about the topic at hand (Clark and Brennan, 1991). This is especially true when the focus of interaction is a physical object. Grounding activities aim to provide mechanisms that enable people to establish and maintain common ground (McCarthy et al, 1991; Sallnäs et al, 2007). Deictic references, like "that", "this", "there" is one kind of grounding activity that direct the partner's attention to a specific object. Maintaining common ground is also shown to be much easier when collaborators can make use of this kind of references (Burke and Murphy, 2007). The importance of providing the possibility to gestures and gaze for deictic referencing in collaborative environments has been acknowledged in a number of studies (Cherubini, 2008; Ou et al, 2003; Kirk et al, 2007; Fussell et al, 2004). In neither of these however, have haptic feedback been utilized for gesturing. It has been pointed out that it is not simple deictic referencing that makes collaboration more efficient, by replacing time-consuming and verbose referential descriptions, but that more complex representational gestures are needed together with simple pointing (Fussell et al, 2004). We argue that the need for addressing both deictic referencing and guiding is a result of the previous statement. Guiding is a broader concept that implies that not only a single action like a deictic reference is made but that a whole sequence of temporally connected events are shared, sometimes including deictic referencing. The concept of guiding as opposed to that of guidance is especially appropriate to use in a collaborative situation involving haptic feedback that is reciprocal, like when a guide dog coordinates its movements with a blind person. Guidance is a commonly used word that is very useful in learning situations (Plimmer et al, 2008). Apart from pointing Clark (2003) argue that placing oneself in relation to other persons and the context as well as placing objects is equally essential indicative acts as pointing. The haptic modality is unique in that it is the only modality with which a person can both modify and perceive information simultaneously in a bilateral fashion. We argue that the implication of that for communication is clear. Two persons holding on to the same object can communicate their intention and perceive the other's intentions by haptic feedback almost simultaneously. In this process both pointing and placing acts are made jointly. A number of studies on collaboration have shown that haptic feedback improves task performance and increases perceived presence and the subjective sense of social presence (or togetherness) for different application areas in shared virtual environments (Ho et al, 1998; Basdogan et al, 2000; Durlach and Slater, 2000; Sallnäs et al, 2000; Oakley et al, 2001). In one study the interaction between visually impaired pupils and their teachers was investigated (Plimmer et al, 2008). This study investigated the effects of training handwriting using haptic guidance and audio output to realize a teacher's pen input to the pupil. However, gesturing including deictic referencing has not been specifically addressed in these studies.

3 The Collaborative Environment

The examples presented in this paper are all based on two evaluations. In one of the evaluations, a haptic and visual application that supported group work about geometry was used (figure 1). In the other evaluation, two versions of a haptic and visual application that supported building with boxes were compared of which one version also included auditory feedback (figure 2). All applications build on the same functionality and all versions of the application are developed for collaborative problem solving. In the applications, the collaborative environment is a ceiling-less room seen from above. Two users can interact at the same time in the environments. Both users have a phantom (3 DOF haptic device) each (figure 1) and apart from feeling, picking up and moving around objects they can also feel each others' forces on a joint object when pulling or pushing it and they can also "grasp" each other's proxies and thereby feel pulling or pushing forces. In one version of the application shown in figure 2 the audio cues were; a grasp sound when pushing the button on the Phantom pen in order to lift an object, a collision sound when an object were placed on the ground, a slightly different collision sound when an object were placed on another object and a locate sound that made it possible to know if the other person's proxy were on the left or right side of your own proxy in the virtual environment.

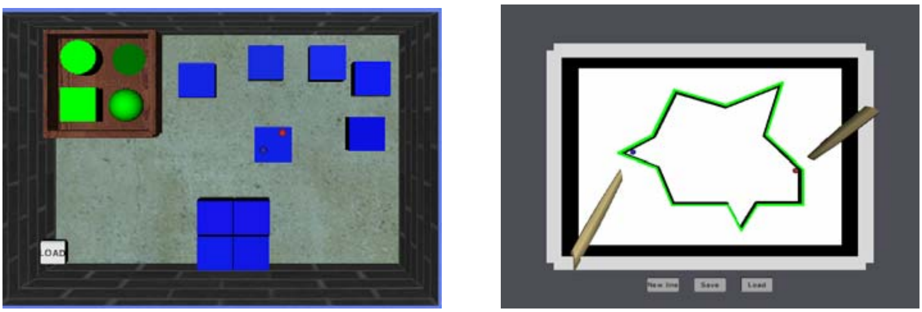

Fig. 1. On the left, two users represented by a blue and red sphere are moving objects in order to cover an area. On the right, two persons are classifying angles using one pen-like proxy each.

Fig. 2. Haptic collaborative application in which both users can pick up and move around objects (small picture in picture). Two users are seen using one haptic feedback device each.

Two evaluations have been performed with this application, which will only be described briefly and related to in the text when needed. In the first study four groups of three pupils (12 in total), of which two were sighted and one was visually impaired, in primary school collaborated in building simple geometrical constructions (Sallnäs et al, 2007). In the second study 14 pairs of sighted and blindfolded university students (28 in total) collaborated in solving mathematically oriented building tasks. Visually impaired people were not recruited to the second study (in which the application version with the audio interface were used) even though it would have been better than blindfolding sighted people. More participants were however needed, than could be found in that target group at that time. In basic research regarding the effects of auditory information on the time to perform two tasks together, it can reasonably be assumed that the overall communicative functions of haptic and auditory feedback are the same for visually impaired and blindfolded sighted people. The general level may be different, but if a parameter has an effect on non-handicapped people, it can be expected to also have an effect on visually impaired people. Especially so, when the context is collaboration between a sighted and a visually impaired person. In that situation, both the communicative frame of reference of the sighted and the visually impaired person have to be taken into account.

4 Communicating Using Haptic Deictic Referencing

4.1 Deictic Referencing as Grounding Strategy in Haptic Interfaces

In the study where pairs of sighted and blindfolded students performed tasks in the application, the potential of the haptic feedback for deictic referencing in the early faces of exploration was shown. In one of the two tasks in particular, where the pair should collaborate in building a cube out of smaller building blocks, deictic referencing was utilized by the blindfolded participant in most of the groups in order to point at objects. The following transcript excerpt illustrates how haptic feedback is used to form a common frame of reference.

Sighted:	*Can you feel how big they are?*
	[Blindfolded moves around the cube for a while]
Blindfolded:	*These might be 2x2x2*
Sighted:	*Yeah, I guess so. But it seems we have five of these 2x2x2 actually, but they are in two different colors, green and blue, so there has to be some difference between them*
Sighted:	*What is the difference?*
Blindfolded:	*The height is more on this one*
	[Blindfolded follows the edges of a blue block]
Sighted:	*It's high?*
Blindfolded:	*Yeah it's longer*

In the above dialogue excerpt the pair is building up a common frame of reference by going through and exploring the different objects present in the scene. Deictic referencing supported by haptic feedback is used in especially two places above, when the collaborating partners want to agree on the dimensions of two different building blocks. When the blindfolded moves the proxy over the edges of the blocks as he says "this one" and "These might be…" he makes it possible for them to talk about and focus the attention on the respective block. Thus, even though the blindfolded did not have access to the visual information on the screen the haptic feedback made it possible for them to build a common frame of reference. The above example shows that the haptic feedback can support direct object referencing in order to create a shared mental model of the workspace. Another typical example of direct object referencing is when the blindfolded indicates a specific object by repeatedly moving up and down with the proxy above it. This is yet another way of focusing the sighted's attention to a specific object of interest. In the same study as referred to in the above excerpt the blindfolded participant often used an indicative act in order to get attention or to place themselves in the work space. One illustrating example, that also says something interesting about the relation to the feeling of presence, is when the sighted participant in one group did not know where the blindfolded person's proxy was. The proxy could not be seen because the blindfolded person was just exploring behind an object that was being built. When asked about his whereabouts, the blindfolded person moved under the object until he felt the end of it after which he moved up and down several times in the virtual room saying "Here I am". Thus, he used the haptic feedback to find out when he was "visible" and in this way he could show where he was. The following dialogue excerpt from the same study illustrates another example of deixis supported by haptic feedback:

Blindfolded: *I think I know…, if we put the…, eh…, 2x2x3 here*
[He moves up and down against the floor where he wants it]

Sighted: *Yeah, ok*
[Sighted participant puts the block in position

Blindfolded: *And then the 2x4x1 here…*
[Blindfolded indicates position by moving back and forth on the floor just under the 2x2x3-block just placed]

Blindfolded: *And then you put the 2x2x2 here*
[Blindfolded indicates position by pointing in a similar manner as before]

In this dialogue excerpt the blindfolded person uses both gestures and direct references to places to indicate where and how he wants the sighted peer to put the different building blocks. When telling the sighted peer where to put 2x4x1-block, in the above example, the blindfolded participant uses a gesture when he moves along the floor back and forth to show the intended placement and orientation of the block. In the other cases he uses the haptic device to point to specific locations in the room, to show to the sighted where he wants the different blocks to be put. This example clearly shows how you can use haptic feedback for direct referencing to locations.

4.2 Deictic Referencing by Haptic Guiding

One of the most important findings from the two studies was that different kinds of haptic guiding have a great potential for deictic referencing when it comes to supporting collaboration in haptic interfaces. Two kinds of haptic guiding have been evaluated in the studies. First, two users can hold on to the same object and feel each other's forces on it enabling them to drag each other around. The second kind of haptic guiding function enables a user to actually grab the other one's proxy directly by pushing a button on the phantom when the two proxies get into contact with each other. The following example, from the study with sighted and visually impaired pupils where a visually impaired pupil and a sighted pupil respectively collaborated in solving some simple geometrical tasks, clearly shows the benefit of using haptic guiding for deictic referencing:

Sighted: *All right, you can pick that one you have now*
[The visually impaired pupil picks up the cube]
Sighted: *And then, …, wait, …, a little bit more to the right.*
Up, take it up a little, …,
[The visually impaired pupil moves up towards the roof]
Vis. impaired: *No, it does not work*
[The sighted guy picks up the same cube to help]
[They move the cube towards them]
[They move the cube a tiny bit to the left]
[They place the cube to the right of another one]
[They fine-tune the cube's position]
Sighted: *That is good!*
[The visually impaired and the sighted pupil let go of the cube]

In the above example the pair of pupils tries out different ways of collaborating when placing a cube in a certain position. The sighted pupil starts out by trying to give direction cues verbally that, according to the visually impaired pupil's utterance, did not work very well. You can see from the excerpt that giving verbal guiding can be cumbersome and the verbal guiding part of the example is actually much longer than shown above. However, when giving verbal guiding did not work the sighted pupil grabbed the same object as the visually impaired pupil held and started to give haptic guiding. As the visually impaired pupil held on to the cube her sighted peer dragged it around and placed it in the correct location. In this way the sighted pupil could use haptic guiding to physically help the visually impaired pupil. Another interesting remark that can be made from the above example is that no one is saying anything during the haptic guiding operation. The haptic guiding function replaces the verbal guiding and in several cases it has been shown to save a lot of time and shift the focus from directing the visually impaired pupil to the actual task at hand. The same conclusions could be drawn from both studies. The following dialogue excerpt is yet another example of haptic guiding, taken from the study with sighted and blindfolded students:

[Sighted grabs the blindfolded's avatar]
[He drags the blindfolded to the beginning of an L-shape, consisting of two 4x2x1 blocks making a 90 degree angle]
Sighted: *Now, here we have an L-shape..*
[Sighted drags the blindfolded to the top of the shape]
Sighted: *… this is the top.*
[Sighted now drags the blindfolded back and forth on the L-shape's north-southern part a few times]
[He then drags the Blindfolded to the east, until the shape ends]

Sighted: *Ok, and this is the bottom right... and then we have this cube that is taller than the others*
[He drags blindfolded up and down on a tall block placed beside the L]
Sighted: *We have another one just like it*

The example above is taken from the early phases of exploration. As preparation the sighted person had organized the two 4x2x1-blocks in an L-shape and he had also put some other blocks beside the L. In order to show the blindfolded the different blocks and their dimensions the blindfolded then grabbed the blindfolded's avatar directly and dragged him around the different building blocks. This example clearly shows the potential for a haptic guiding function for deictic referencing when it comes to collaboration between sighted persons and persons who lack vision.

5 Communicating with Sound

In the experiments with sighted and blindfolded students, sound functions were also evaluated. One of these was a sound that was heard whenever one of the users pushed the button on their respective phantom. The purpose of this, so called, contact sound was to indicate (in stereo) where the sighted person's avatar was in the environment. The auditory feedback was used for dectic referencing in a similar way as when someone knocks on something and says "here" or "this one". The following dialogue example shows this function in use:

Sighted: *Pick up a new cube*
[Blindfolded locates a cube on her own]
Blindfolded: *That one?*
Sighted: *Yeah...And then you can move here...*
[Sighted uses sound to show the way]
[Blindfolded navigates to a place slightly above the intended one]
Sighted: *Ok, down a bit..., down..., stop*
[Blindfolded releases]

In the example, the sighted person makes use of the contact sound to give information about in which direction the blindfolded should move and hereby the blindfolded is guided to approximately the right location. As stated earlier, giving verbal direction cues often is quite cumbersome when one of the collaborating partners cannot use their sight. The contact sound cue facilitates the collaboration since the position to go to is indicated by the sound instead. Thus, auditory deixis can be used to replace verbal communication and shift focus to issues more vital for the task at hand.

6 Discussion

The examples presented in this paper clearly show that the haptic feedback can convey so much more information than just the "feeling" of virtual objects. When two people collaborate in a haptic interface, like the one evaluated in our studies, it is evident that the haptic feedback also can be used to communicate both intentions and information much in the line with Cherry's (1957) definition of communication. The examples have shown that the haptic feedback facilitates grounding during the early phases of exploration, especially through the use of deictic referencing as Clark (1996) suggests that gesturing does. We have also shown that added guiding functions can aid the collaboration in a haptic environment considerably, especially when one in the team lacks sight that has also been shown by Plimmer et al. (2008). By using haptic guiding (holding on to the same object or dragging the other user's avatar directly) one can communicate information about direction that does not need to be verbalized. It is shown in the examples that collaboration and joint problem solving becomes much easier when you do not have to focus on constantly giving direction cues. The examples used in this paper are all based on studies where one of the collaborating partners has been blindfolded or visually impaired. However, much of the findings reported here could surely be applied to pairs of sighted persons as well.

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