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Influences of haptic communication on a shared manual task

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ABSTRACT

With the advent of new haptic feedback devices, researchers are giving serious consideration to the incorporation of haptic communication in collaborative virtual environments. For instance, haptic interactions based tools can be used for medical and related education whereby students can train in minimal invasive surgery using virtual reality before approaching human subjects. To design virtual environments that support haptic communication, a deeper understanding of humans' haptic interactions is required. In this paper, human's haptic collaboration is investigated. A collaborative virtual environment was designed to support performing a shared manual task. To evaluate this system, 60 medical students participated to an experimental study. Participants were asked to perform in dyads a needle insertion task after a training period. Results show that compared to conventional training methods, a visual-haptic training improves user's collaborative performance. In addition, we found that haptic interaction influences the partners' verbal communication when sharing haptic information. This indicates that the haptic communication training changes the nature of the users' mental representations. Finally, we found that haptic interactions increased the sense of copresence in the virtual environment: haptic communication facilitates users' collaboration in a shared manual task within a shared virtual environment. Design implications for including haptic communication in virtual environments are outlined.

1. Introduction

Collaborative virtual environments (CVEs) are digital spaces that allow remote users to work together sharing virtual objects (Snowdon and Churchill, 1998). CVEs are used in many applications such as surgery, CAD and architecture. They offer new interaction possibilities by allowing users to share virtual workspaces. However, the design of CVE that support collaboration remains an open issue. For instance, interactions in current CVE rely predominately on vision and hearing. However, little attention has been focused on haptic interaction. Haptic interaction is suited to accomplish shared manual tasks. Our objective is to show that supporting functional haptic interactions in CVE can improve the users' collaborative performance in such tasks. For that purpose, we used a user-centred design methodology to build a CVE that support a shared manual task. Finally, a user study was conducted to evaluate the system and to study haptic communication in CVE.

2. Literature review

2.1. Collaboration and communication

Collaboration is defined as a synchronous common work in which partners share resources and problems to accomplish a common task (Dillenbourg, 1999). When two operators collaborate, they try to share a common mental representation of the situation. This is referred to as the common frame of reference (Hoc, 2001) or the common ground (Clark and Brennan, 1991). Common ground allows the partners to understand each other and to organize their common work. Thus, they can perform different but complementary actions. It is constructed and updated by the grounding process (Clark and Brennan, 1991). This process consists of an ongoing exchange of information and understanding signs between partners to update their common ground. It helps them to understand the partner's actions and to plan their shared actions. The choice of the appropriate communication channel to build the common ground is dependent on the situation. In this context, manual tasks involve invisible elements such as haptic sensations. Therefore, they are hard to exchange only through a verbal description and require the use of additional communication means like the haptic channel. Our objective is to investigate

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the role of haptic interactions for the common ground construction when two operators perform together a manual task.

2.2. Haptic communication

Unlike other nonverbal communication forms such as facial expressions and eye contacts, little attention has been focused on haptic communication. With the advent of new technologies, the research community has given new consideration to the haptic dimension of mediated communication (Buxton, 1995).

Compared to vision or hearing, haptic feedback is a more direct human–human interaction. It can be used to express feelings of closeness or intimacy with another person (Sallnäs et al., 2000). Several researches show that the sense of touch increases social interactions (Haans and IJsselsteijn, 2006) and trust (Bailenson and Yee, 2008). For instance, it has been shown that a person is encouraged to participate in a course when touched by a teacher (Guéguen, 2004).

Beyond this social dimension, one can consider the functional dimension of haptic interactions to communicate complex motor behaviors. Indeed, Rasmussen (1983) distinguishes three categories of human behaviors; skills, rules and knowledge. The sensory-motor performances are situated in the skills level. This level of knowledge is considered as an inexpressible or a reflex behavior: "We can show the ability, but cannot explain the way to achieve it" (Rasmussen, 1983). Actually, verbalizations can permit to communicate the correct rules to accomplish a manual task (declarative knowledge). However, it can hardly be used to communicate efficiently haptic sensations: information about the forces and the movements they perform (procedural knowledge). Operators use then the haptic communication channel to exchange such information. This can be observed in several manual tasks such as lifting a table together or guiding the partner's hand to teach motor skills (Reed et al., 2005). In these situations, physical contacts represent a shared symbolic meaning for the person who initiates the touch and the person who receive it (Haans and IJsselsteijn, 2006). This allows them to synchronize their actions towards a common goal. It helps them also to develop an efficient haptic common ground when performing the manual task.

To design haptic collaborative systems, it is important to understand how distant interactions can influence haptic communication. This will be discussed hereafter.

Several existing systems support mediated haptic communication. These applications can be divided into two main categories.

2.2.1. Human–computer interaction systems

Haptic devices can serve as an input device as well as a force display device, enabling users to physically interact with virtual objects and to feel the environment feedback. Thus, they are used to transmit a wide range of information to the users.

Haptic devices are used in HCI to transmit simple information to the users such as spatial/directional information by means of vibrotactile stimuli (Brewster and Brown, 2004; Van Erp, 2005; Brayda et al., 2010). They are also used to teach motor skills in virtual spaces such as: handwriting (Yoshikawa et al., 2000), a crane-moving task (Gillespie et al., 1998) or to help users to memorize a force sequence (Morris et al., 2007).

However, human–computer interaction systems neglect the communicational dimension of haptics. In this paper, we try to overcome this limitation by focusing on human–human haptic interaction and communication.

2.2.2. Interpersonal haptic communication systems

Compared to other modalities, haptic communication requires physical contacts to transmit information. However, physical contacts are hard to reproduce faithfully at a distance. This can limit the use of touch for mediated interpersonal interaction. With the advent of new devices, haptic communication becomes feasible, even remotely. We talk than about the metaphor of haptic mediated communication. It is defined as: "the ability of one actor to touch another actor over a distance by means of tactile or kinesthetic feedback technology" (Haans and IJsselsteijn, 2006). In this paper we focus mainly on haptic interaction in CVE. For a survey of existing communication media that support social haptic interactions see Haans and IJsselsteijn (2006).

In the area of CVE, few studies addressed haptic communication. Researches in this domain focus mainly on the effects of this communication modality on task-performance (Basdogan et al., 2000; Sallnäs et al., 2000). These studies show that haptic communication can improve users' performance in manual collaborative tasks. They show also that haptic interactions have positive effects on the sense of presence in virtual environments (Sallnäs et al., 2000) and the sense of copresence with a remote partner in a CVE (Basdogan et al., 2000). Partners enjoy the communication experience through the haptic sense and feel more confident when interacting with each other. In Gunn (2006), the author described a system that allows two remote artists to work together on a common virtual sculpture. However, only a subjective evaluation of the system was presented.

Most of the previous works focus exclusively on the effects of haptic communication on task-performance and on presence. However, there are several other issues that still need to be addressed in CVE: (i) nature of information being exchanged through the haptic channel, (ii) meaning people give to this information and (iii) effects of this information on collaboration. The paper aims to addresses these questions.

3. What You Feel Is What I Feel: WYFIWIF

Several benefits of mediated haptic communication are mentioned in the literature. According to Rovers and van Essen (2004), the haptic channel can compensate the loss of non-verbal cues that results from the use of current communication media. The media richness approaches go further by claiming that the addition of more communication channels will always enrich communication. However, this is dependent on the task (Navarro, 2001). Indeed, Brave et al. (2001) show that the effects of haptic communication depend on the context in which it is used. The additional haptic information must then contribute to the development of the common ground to enhance communication. Otherwise, it becomes a source of ambiguity and incomprehension between partners. We believe that the combination of communication channels do not only contribute to increase the amount of the exchanged information, but must also allow the partners to develop a more efficient common ground. This requires partners to develop a shared meaning for the exchanged haptic information and to consider the functional dimension of touch.

3.1. Paradigm description

In order to design a haptic communication system, one must consider the users' roles and the characteristics of the collaborative task in which they will be involved. In this paper, we present a user-centred design for a CVE that takes into account these parameters.

To support haptic communication, a system based on the WYFIWIF (What You Feel Is What I Feel) paradigm (Chellali et al., 2010) was developed. WYFIWIF (Fig. 1) allows two users to exchange haptic information (forces and movements) even remotely. It supports also other communication forms (visual and verbal) in the CVE. One user (the actor) interacts directly with the virtual