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Comparative study of the bimanual and collaborative modes for closely coupled manipulations ☆

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ABSTRACT

The interactive manipulation of complicated environments poses a real challenge since it involves the simultaneous management of several heterogeneous constraints. For instance, molecular design requires the simultaneous control of several connected kinematic structures, with strong physical and chemical interactions, to provide the relevant conformation and docking solutions. This paper investigates two working strategies for carrying out closely coupled manipulations in such environments. We present an experimental study which compares bimanual and collaborative configurations. For both strategies, we provide users with the same number of resources, such as the same visualization system and the same number of manipulation tools. The performances are better in the collaborative configuration for the simultaneous management of several constraints and the manipulation of distant regions. However, this working strategy involves a strong communication flow to coordinate the actions. The performances are better in the bimanual configuration when the tasks involve a limited working space and a low level of constraints.

1. Introduction

Nowadays, there are many complicated problems that are not solvable by only one person. In fact, the cognitive and working capacities of a single human are limited. Collaborative Virtual Environments (CVEs) introduce new methods with new tools allowing the association of several partners in the same problem-solving task. These approaches pose a real challenge since they involve different fields, including Information and Communications Technology (ICT), hardware and software shared platforms, and social and psychological studies.

Among complicated environments, molecular design and docking simulations are suitable applications for the emergence of CVE approaches (Bolopion et al., 2009). The current tools for molecular design allow the prediction of new molecular complexes and thus the development of new drugs and medicines. However, the analysis of the relevant molecules is a complicated task for biologists, both from the point of view of the physical phenomena involved and of the topological complexity. It requires the interpretation and manipulation of a large number of Degrees of Freedom (DoF) and physical parameters which can go beyond the abilities and the skills of a single biologist. Furthermore, these tasks are based on several areas of expertise such as modeling expertise for the structural and flexibility features, and biological expertise for the functional features. Therefore, a possibility is to introduce two or more partners simultaneously in the docking process in order to analyse, explore, and find a docking configuration for these huge molecules.

Since the emergence of protein databases during the 1970s and 1980s, different solutions allowing several biologists to simultaneously study and manipulate molecules and chemical structures have been developed. For example, Bourne et al. (2008) propose the internet platform "MICE" to edit collaboratively molecular descriptive files. It is merely a text based asynchronous collaboration. Dove et al. (2005) developed a similar platform with advanced functions (chat and videoconferencing). However, these approaches concern asynchronous manipulations without direct interactive manipulations between the partners. These working configurations inhibit or limit important collaboration features such as communication and real-time synchronization.

With the recent advances in communication technologies, several synchronous solutions have been proposed to support these kinds of tasks. Kriz et al. (2003) proposed an immersive synchronous platform for the manipulation of elementary chemical structures. However, they mainly discussed some technical issues due to the network latency and not the collaboration constraints. Later, Chastine et al. (2005) investigate some communication issues, and more specifically the inter-referencement, involved in the pointing of atoms in simple static molecular

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simulations. They proposed new visual metaphors to enhanced inter-referencement in CVE.

Although these works provide suitable environments for synchronous and multi-user interaction with molecules, no research has really investigated the role of CVE in supporting efficient and reliable collaborations. More specifically, there has been no investigation of sharing the workload between the partners involved, resulting from the manipulation of such complicated environments compared to a bimanual manipulation (one user using his two hands).

This paper proposes investigation of these factors in the collaborative manipulation of molecular structures requiring a highly synchronous management of spatiotemporal constraints. This complicated task requires handling a molecular structure while taking into consideration the attractive forces between other structures of the molecule. Thus, it involves a close collaboration between the partners and a highly synchronous coordination of their actions to achieve effectively the required deformation. This paper aims at highlighting some important factors to be taken into consideration for a CVE for molecular design.

The present paper is organized as follows. Section 2 reviews papers which have investigated some factors of bimanual manipulation and CVE. Section 3 develops the investigated task and its role during the docking process. Section 4 presents the objectives and the working hypothesis of this research. Section 5 presents the hardware setup and apparatus. Section 6 presents the experimental protocol. Section 7 develops the results and discusses the contribution of the several features of a collaborative configuration to the fulfilment of complicated tasks. Finally, Section 8 summarizes the contribution and presents some issues and prospects for collaborative molecular design.

2. Background

2.1. Bimanual and collaborative

We can ask ourselves whether two heads are better than one? This is the question addressed by Meudell et al. (1992) and Thompson (2002). Meudell et al. compare pairs of participants and solo participants in a memory test. The results do not show any difference between the two experimental configurations. However, Thompson highlights that we should compare two heads interacting and two heads without interaction or communication: this configuration would evaluate the real impact of the collaboration. Her review of this subject does not conclude with any firm results about improvements in collaboration.

However, no study seems to have addressed the difference between bimanual interaction and a collaborative configuration. Bimanual interaction can be considered as an interactive process (interaction between hands through the brain) although it is a *one head* process. This is the new dimension of the question “are two heads better than one?”.

Bimanual interaction can be either symmetric or asymmetric. When the hands have the exact same function, it is called a symmetric bimanual interaction (Balakrishnan, 2000). However, Guiard's (1987) theory explains that bimanual interactions in daily life are mainly asymmetric (dominant and non-dominant hand). In this paper, we will compare participants on the same platform (alone or in pairs). We provide identical tools to avoid an asymmetric collaboration which is not a well-known problem in the literature. The consequence is that we will work on symmetric bimanual interactions.

Some studies have investigated symmetric bimanual interactions and measured some of their limits. Covington (2009) proposes an improvement to help the bimanual task of path finding: he notices improvements in the overall completion time at the cost of movement accuracy and individual completion time. Maier et al. (2010) propose a tangible interface with augmented reality to carry out the docking of basic chemical structures. They conclude that there are two different ways to improve bimanual interaction: improving the interaction tools or adding more individuals.

The research presented in this paper is a first attempt to compare the bimanual and collaborative configurations. In order to avoid a bias in the experimental protocol, it is a symmetric bimanual configuration which may not be optimal but is at least comparable to a collaborative configuration.

2.2. Collaborative virtual environments

The potential of collaborative spaces has been previously investigated in several studies. For instance, de Oliveira et al. (2002) exploit CVE as a medium for industrial training and electronic commerce. Jensen et al. (2007) explore several CVE solutions for scientific visualization and distance learning: they show the limits of distant collaboration in terms of communication. Lidal et al. (2007) propose HydroVR, a flexible CAVE platform for the collaborative review of projects on geological resource prospection; their main purpose was to create a collaborative environment where all experts can carry out a discussion. In these studies, the partners can collaborate through several configurations, such as supervision and reviewing configurations, and mainly exploit a high level of communication, such as verbal communication, to coordinate the activity. However, all these papers mainly investigate low physical coupling strategies where the involved experts combine their skills and knowledge to solve the problem without a synchronous and/or physical interaction between them.

Recently, new applications involving interactions between partners have emerged. These works mainly investigate multimodal feedbacks to support various types of communication for the interpersonal awareness and to improve the co-presence (Sallnäs, 2004, 2010). For instance, Başdoğan et al. (2000) study the role of haptic feedback for the collaborative manipulation of shared objects and show an improvement of performance when participants physically feel each other. Sallnäs et al. (2000) and Iglesias et al. (2008) investigate the awareness and co-presence processes during the simultaneous manipulation of simple 3D objects; they also show an improvement when participants are well aware of each other's presence. Nam et al. (2008) introduced audio and haptic feedbacks in a *hockey air* virtual game and improved the feeling of co-presence.

However, our study is focused on bimanual interaction, which is mainly useful in tasks requiring a high level of interactive coordination. A few studies have tried to investigate closely coupled collaborations, where each action could immediately modify the environment of the partner. For example, Plimmer et al. (2008) propose a system to help visually impaired students learn to write with audio and haptic guidance. This task requires a strong coordination of its actions, although it is an asymmetric collaboration as the students are passive haptic users.

McGookin and Brewster (2007), Moll and Sallnäs (2009), and Moll et al. (2010) investigated both tasks presenting symmetric collaborations for the manipulation of charts and for the manipulation of 3D objects respectively with improved performances. They both proposed haptic and audio metaphors to reduce the level of conflicting actions. However, they mainly explored the manipulation of elementary 3D rigid objects, which only requires the synchronous management of geometrical constraints.

To summarize, several works have investigated collaborative tasks presenting different levels of coupling between the partners. However, they have mainly investigated tasks requiring the management of elementary geometrical constraints. Moreover,