A preliminary study of two handed manipulation for spatial input tasks in a 3D modeling application

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Abstract We developed a free form deformation application for an immersive environment in which users can interact freely using data gloves. To ensure better comfort and performances, we added the possibility of bimanual interaction in our environment. To investigate the actual gain obtained by this interaction technique we designed an experimental protocol based on spatial input tasks. In our experiment, we asked our subjects to use only the dominant hand to achieve the different tasks or, on the contrary, to use both hands. Comparison of users' performances – i-e, time and precision – shows that, without proper training, executing a task using two hands can be more time consuming than using one hand. In fact, the degree of symmetry of the tasks performed with each hand seem to have a significant impact on whether or not users take advantage of bimanual possibilities. Our results also show that bimanual interaction can introduce proprioceptive cues that can be of help to achieve more precision in the placement or selection only when proper visual information are missing.

1 Introduction

Virtual Reality and 3D interaction are often presented as a major step towards real direct and intuitive manipulation. Indeed, Immersive Virtual Environments (IVE)

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allow users to interact with virtual objects using everyday actions and commands. For example, users can manipulate – i.e. grab, move, rotate, etc. – an object using their bare hands, as they would with a real object. *It is also possible to explore 3D scenes at real scale, allowing to experiment total immersion in a virtual world.* This has proven to be be useful to enhance users understanding of the environment explored. For example, a large scale multimodal virtual system for archeological purposes has proven to be efficient during an exhibition for the public whose aim was to teach the process of constructing columns as part of the structure of an ancient Greek temple [4].

However, the evolution of virtual environments seem disappointing, with few actual applications. The main application field seem to be information visualization and virtual scene exploration. But except for a few examples, and despite all the efforts provided, interaction with the environment in this kind of applications generally remains poor, and frequently needs specific interaction metaphors for each task (sometimes integrating the use of physical devices, "props", to complete the task). It seems that major manipulation and perception problems remains, despite an early identification of these difficulties in precocious studies on virtual reality [17, 5]. At present time these specific issues still need to be addressed before drawing a real profit from IVE potentialities. For example, no effective solutions have been provided for effective spatial selection and input in IVE graphical applications : techniques are usually poor and lack of precision and efficiency. Exploiting bimanual interaction and proprioception have been suggested and are promising solutions to some of the known fundamental issues [2, 7, 10, 14, 18].

We developed a free form deformation application called *OMM* that allows a user to perform simple 3D modeling tasks in IVE using datagloves. Our objective with this application is to provide a set of intuitive and efficient interaction techniques to realize simple modeling tasks. Relying on previous studies, showing the potential manual and cognitive benefits obtained from bimanual interaction [11], we developed several bimanual interaction techniques for deformation tasks. In this paper we propose a preliminary survey investigating the benefits of some basic bimanual interaction techniques in IVEs for 3D input. Our study aims at investigating whether bimanual interaction can be used as a significant improvement towards effective and convenient spatial input in IVE, and how they influence the users' performance and comfort.

2 Bimanual Interaction

The justification of research interest in bimanual interactions seems obvious. We spontaneously use bimanual interactions to ensure efficiency, precision, comfort in the realization of everyday tasks. Thereby, bimanual interactions techniques are becoming more and more present in 2D applications, and have been exploited to lead to intuitive interactions modalities in IVE (e.g. two handed ray-based interactions

[18], over the shoulder deletion and two hands flying [13], two-handed selection techniques for volumetric data [16]).

The *Kinematic Chain Theory* [6] provides a theoretical framework to describe bimanual techniques. Guiard propose that two hand interaction can be *symmetrical* or *asymmetrical*. In *symmetrical tasks* the two hands perform the same action. In *asymmetrical tasks* each hand performs a different action. In that case the non dominant hand usually sets the frame of reference for the action of the right hand. Our interaction modality, manipulating objects using non dominant hand while deforming with dominant hand, is based on these principles : the user can use the non dominant hand as a reference frame to correct dominant hand gesture [1] and make precise manipulations on an object.

As well, using bare hands to achieve a task can bring gains in motor efficiency and lower cognitive load. In bimanual interaction motor efficiency is mainly due to *parallelism* i.e. the simultaneous execution of the two tasks assigned to each hand. According to Buxton and Myers, there's a correlation between degree of parallelism and performances [3] : the results of their study show that it is possible to improve users performance by splitting the sub-tasks of compound continuous tasks between the two hands. This procedure leads in improvement of performances for both novices and experts users. Their study also show that when the two hands are used sequentially, each one making separate tasks, using both hands can avoid time consuming task switching, thus reducing task completion times.

However, these encouraging results must be taken with proper care considering the fact that the expected benefits may depend on the interaction device or input modalities, on the subtasks involved in the task and on the environment [10]. For example, a study realized on a docking task necessitating manipulation and navigation in an IVE showed no significant gain from bimanual interaction [8]. In their comparison of a 12 degrees of freedom device to a time sequential two-handed input Huckauf et al. found no significant differences even though there was a slight trend towards better performance for the simultaneous two handed input.

In addition, bimanual interaction introduces *proprioception* in the environment. Proprioception is the sense of the relative position of neighboring parts of the body. Using a persons' sense of position and orientation of his body and limbs can be exploited as an additional sensory-motor channel that provides useful information to the user [13].

3 *OMM*: a 3D Modeling application

3.1 Manipulation paradigm

Free form deformation applications (FFD) in IVEs (i.e.manipulating three dimensional forms freely in a 3D environment, allowing designers to grab and deform free formed surfaces at any point of the surface) were considered has an important breakthrough towards more efficient and intuitive design interfaces [19].

As a matter of fact, in these environments, users can experience an unmediated direct manipulation situation [15]. Assuming that the actions are performed directly on the objects by the user with is bare hands, the environments do not necessitate to act through artifacts such as display control points, widgets, icons, etc... In that extent it shortens the *distance* (between ones thoughts and the physical requirements of the system under use) and increases the *engagement* (the feeling that one is directly manipulating the objects of interest) [9].

3.2 The Odd Mesh Maker application

Our protocol implementation is based on *Odd Mesh Maker*, a deformation application based on the *Twister* deformation model [12], in which users can freely perform deformation on 3D objects using their hands.

A deformation is defined by a deformation volume and a deformation function. The user uses a data glove to interact with the environment, position the starting point of the deformation gesture and control the deformation shape (see figures 1, 2, 3).

A two handed deformation modality has also been created in which the two hands can be used simultaneously (figure 4) or alternatively to manipulate or warp an object.

Our objective with this application is to develop an environment that proposes 3D modeling tools that will not require ad hoc devices to interact. In that purpose we developed a wide range of tools that allows a user to rotate, translate, replace, add... objects with the sole use of the datagloves as an interaction device. Since these tools are still under an evaluation process, we will not present them further here.

4 Design study

This study aims at investigating whether using bimanual interaction can improve performance in spatial input tasks, and how proprioception can be exploited to enhance users control over the task. In this section, we present our experimental setup and the hypothesis we investigated.

4.1 Subjects

We selected 8 subjects with no prior experience with IVE. They were divided in two groups : group 1 achieved the two tasks using only the dominant hand, group 2 had

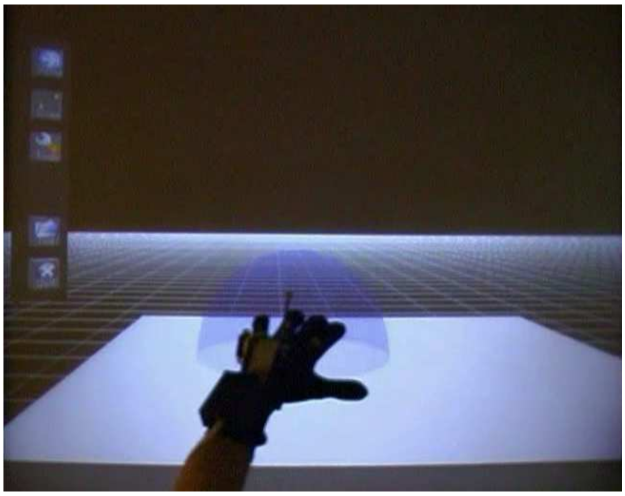

Fig. 1 An influence sphere is attached to the users' dominant hand. The deformation area is defined by the intersection of the selection sphere and the surface.

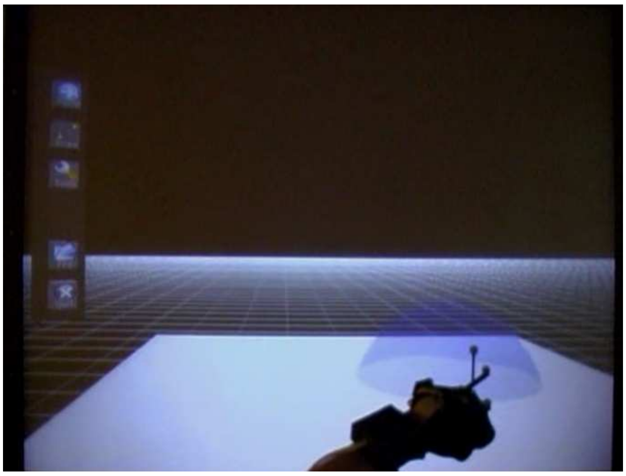

Fig. 2 By grasping the surface the user validate the warped area.

to use both hands. All subjects were right handed and had normal or corrected to normal vision. We first presented the FFD application and hardware device to the subjects. We then allowed them to use it freely for a few minutes period. During this training session, they were allowed to use both unimanual or bimanual interaction to perform a deformation.

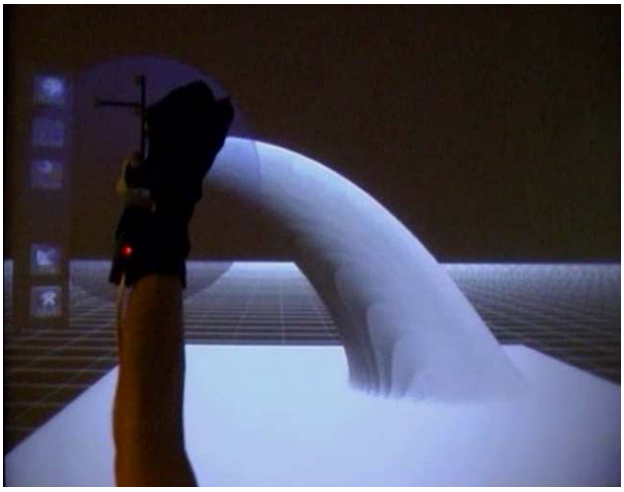

Fig. 3 The deformation is defined by both the position and orientation of the hand at any moment during the deformation gesture.

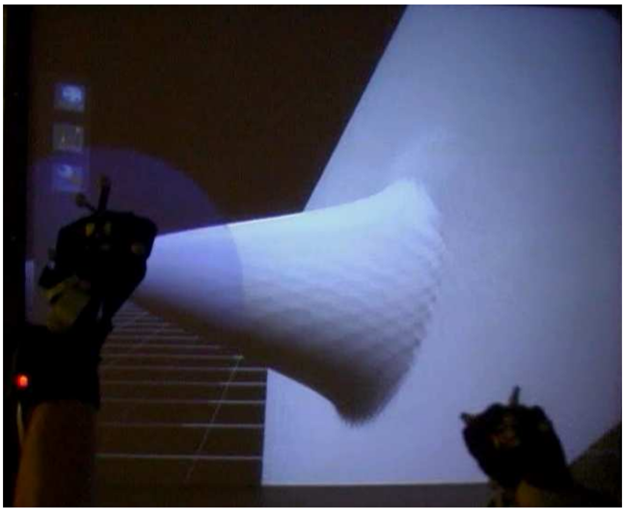

Fig. 4 Deformation tasks can be performed using both hands, here in asymmetric situation. The use of both hands is expected to increase users control over the deformation and gesture range.

4.2 Apparatus

Experiments was conducted on a Barco Consul, a semi-immersive Virtual Reality environment using stereoscopic display – resolution 1400x1050, refreshed at 100Hz – and CrystalEyes CE-2 glasses. Images were generated using two HP Workstation XW8000 – one for each screen – fit out with a 3Ghz Quad Xeon and a NVIDIA

Quadro FX 3000. Head and hands tracking is ensured by the ART tracking system and magnetic trackers. Users used 5DT Data Gloves to interact with the virtual reality environment. Every results are rounded to centimeter because of tracking system's precision.

4.3 Tasks

Subjects were asked to achieve two different tasks; each task was repeated sixteen times.

In the first task, the *designation task*, the subject had to interact with a cube placed at a random position in the workspace. One at a time, each of the four corners belonging to the face in front of the user was highlighted by a red coloring. The user was required to grab – or designate – highlighted corner as precisely as possible, and make a deformation to validate designation. During this session, the dominant hand of the user was surrounded with a colored sphere representing the deformation area. This sphere was here to help the user perceive the volume of the cube that would be influenced by the deformation. The user perfectly grabbed the corner when the center of the sphere attached to the user's hand perfectly matched with it. In the first condition the user could only use the dominant hand to grasp the corner, while in the second condition, the user could manipulate (move and orientate) the object with the non-dominant hand while the dominant hand would grab the highlighted corner. We hypothesized that the use of the non dominant hand would bring higher comfort and efficiency in this designation task, leading to shorter completion times and higher accuracy. The accuracy was measured using the Euclidean distance between corner and center position.

In the second task, the *docking task*, two spheres were presented in the user's workspace. A red colored sphere represented a fix target, and a white colored sphere was to be manipulated by the user. The two spheres were randomly positioned. The user had to grasp the white sphere, and put it in the target. To make a perfect match the two centers had to coincide. In the first condition, the user had to grasp and put the sphere using the dominant hand, in the second condition, the user had to grasp the target sphere using the non dominant hand before grasping the white sphere using the dominant hand. The precision is measured by the Euclidean distance between the two spheres' centers. For this task, we did not expected shorter completion times assuming that the subjects had to realize two separate tasks : grab the target and then grab and drop the moveable sphere. However, we hypothesized higher accuracy for the bimanual condition, assuming that the second hand would allow the subject to exploit proprioception has an additional information to perform the task.

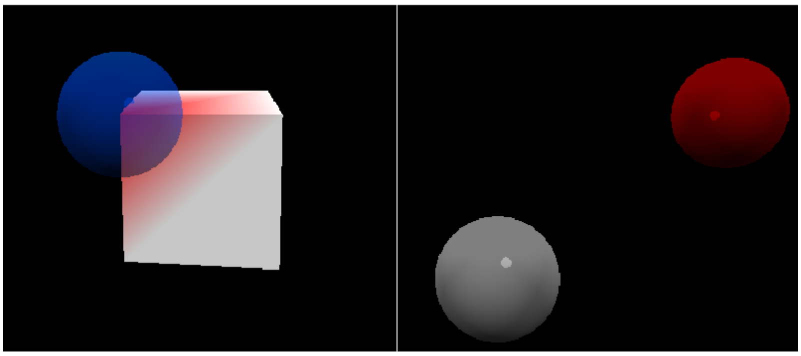

Fig. 5 On the left the *designation task* with the user's sphere in blue, on the right the *docking task*

5 Results

Regarding task completion times in the designation task, while we expected group 2 to be faster than group 1, results show the opposite. For the first task, subjects of group 1 took an average time of 11,43s to designate a vertex while group 2 took on average 17,26s. This result is statistically significant (p= 0,02). For the second task subjects of group 1 took an average time of 25,01s to move the sphere towards the target while group 2 took on average 26,07s (this result was not statistically significant).

Whereas the second result can easily be explained considering the fact that the task necessitates to individually grab two objects, the first one needs to be explained. As a matter of fact, holding an object with one hand while performing an operation on the object with another is a day to day activity. However our results show that it is not so intuitive to realize such a manipulation in IVE. Previous studies showed that the degree of parallelization is dependent of the conceptual integration of both subtask into a single one [14]. This result tends to show that the positioning – using the non dominant hand – and the designation task – using the dominant hand – weren't conceptually integrated as a unique task , which, we hypothesized, would have led to shorter realization times.

If we compare the placement times of task 2 (the time to displace the sphere, after grabbing the two objects) however , we found that group 2 is faster than group 1 (t = 8,33s vs t = 10.88s; this result was not statistically significant). This can explain the lower differences between group 1 and group 2. We think that this may be because in that case the two subtasks converge to the same objective – make the two spheres closer –, which is different from task one, each subtask having its own semantic : orientate and designate.

From this second result we can assume that bimanual interaction can lead to shorter completion times for fully integrated task. However, the first result tend to show that bimanual interaction, although intuitive with real objects, is not fully exploited in IVE. It may be because users need a learning period to integrate both subtasks into one conceptual task which is *make a deformation on a precise vertex*. In our experiment the learning period consisted in manipulating a plan and a cube using one or two hands. Whereas this learning period wasn't limited, almost every subjects took only about 5 minutes to try the different modalities. It probably would have needed a longer learning period for users to fully exploit the whole potential of bimanual interaction.

	Group 1	Group 2	T-Test
$Distance_{tot}$	0.09	0.01	p=0.01
$Distance_x$	0.02	0.01	p=0.06
$Distance_y$	0.03	0.01	p=0.03
$Distance_z$	0.07	0.01	p ¡.001

Table 1 Docking task precisions measures : Euclidean distance, distance along each axis and time needed to place the sphere on the target.

Regarding precision, our results shows no difference between group 1 and group 2 for task 1. The two groups have the same average performance of 7 cm. Performances for task 2 (table 1) show that all distances of Group 2 are smaller than those of Group 1 and are statistically significant (except for X distance). These 2 results seem contradictory : for the 2 tasks, group 1 and 2 differ only in the use of bimanual interaction, but results indicate a positive influence of the bimanual modality in terms of precision only for task 2. We explain this result by whether or not the visual cues provided by the environment are sufficient to perform the task. In fact subjects experienced difficulties for task 2 linked to the dataglove sensitivity for postural detection between open hand and close hand. These difficulties lead to some involuntary drifts of the displaced sphere. It seems that in that case, the non dominant hand presence as a reference was used to improve gesture control whereas in task one only visual information (sphere of influence) were exploited. In task 2 it seems that the subjects actually used proprioceptive information, probably because of the interferences' nature, which were linked to the proprioceptive information about hand position during the target release stage.

Moreover, the gain in precision is more important regarding depth axis. It seems that the subjects' tendency was to place objects at height of sight, leading to occlusion phenomenon that canceled visual information about depth information. In this case, absence of visual cues is overcome using information from proprioception cues : the relative positions of each hand.

6 Conclusions and perspectives

Our results show that bimanual interaction lead to better efficiency and comfort without the need for prior training only under a certain set of conditions. Concerning completion times, it seems that symmetrical tasks are performed quicker. Asymmetrical tasks, on the other hand, did not allow our subjects to take advantage of the bimanual interaction condition. We think that maybe with further practice, subjects would have obtained better performances.

We also found that bimanual interaction introduces proprioception that can be exploited when proper visual cues are missing. For task 1, the groups did not show any differences concerning precision. This, we think, because of the influence sphere we added in OMM. We think that the subjects, in that case, only relied on visual information to perform the task at hand. Yet, proprioception cues seem to have been used when visual information was unappropriate (problems to control the release of the sphere in task 2) or missing (depth information in task 2).

In a future study, we would like to further investigate those results. We will analyze the impact of proper training to exploit bimanual interaction for asymmetrical tasks. We would also like to further evaluate the importance of proprioceptive cues to replace missing visual information. For example, we could intentionally create a lack of visual information, by avoiding the sphere around the subjects' hand in a designation task. We could also create a new task with an environment visually overloaded and see if bimanual interaction helps.

We would also like to investigate the impact of bimanual interaction on the possibility to ensure greater control and precision during the deformation gesture. In a desktop modeling application, users generally refer to several visual cues to control the task at hand. In an IVE, adding the same visual clues could lead to a visual overload that would hinder the activity of the user. We think that it is possible to exploit proprioception to replace certain visual information, thus allowing the user to actually realize the deformation planed without relying only on the visual capabilities of the environment.

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