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Collaborative 3D Interaction in Virtual Environments: a Workflow-Based Approach

Samir Otmane, Christophe Domingues,
Frédéric Davesne and Malik Mallem
IBISC Laboratory, University of Evry
France

1. Introduction

Collaborative Virtual Environments (CVEs) are complex environments where multiple users share the same objects to act together. The complexity of these environments is related to the interaction of the user group with shared items. In a shared world, several constraints appear, including those related to coordination and communication of users and user interaction management in virtual world towards objects and other users. The existing single or multiuser 3D interactions in Virtual Reality (VR) are currently far from providing suitable solutions. Indeed, the 3D interaction suffers from a lack of models and formalisms to manage and control the actions and intentions of users in the virtual environment. The interaction of multiple users with the virtual environment is limited and many researches are in progress. The main objective of the research in the field of multiuser 3D interaction is to instruct users to evolve in CVEs, and to interact together efficiently and easily with virtual entities.

Currently, there are two types of synchronous multiuser 3D interaction techniques. A first category separates the degrees of freedom (DoF) for the object to manipulate. In this case, users operate single user techniques by acting on the degrees of freedom which are assigned to them. For the second category, a function will determine the final movement from the position and orientation of the user object in the CVE. This involves using a new technique in multiuser situations. However, all of these techniques do not take into account the constraints of coordination and communication between users and focus exclusively on manipulation tasks with two users. However, the design of a CVE requires considering multiuser interactions from Computer Supported Collaborative Work (CSCW) point of view, as well as the management of group interactions. Another aspect to consider is the heterogeneity of virtual reality platforms used by participants as well as the disparity between users for providing new models and systems supporting efficient collaborative work and enhancing presence in CVEs.

This chapter presents a useful workflow-based approach to manage 3D interactions and enhance presence in CVEs. This approach combines astutely different concepts from two research domains: CSCW and VR. The second section outlines and discusses the background of recent contributions concerning collaborative 3D interaction techniques. Section three presents some fundamental concepts relevant to the management of group interactions in a CVE. Section four describes and details our contribution concerning a workflow-based approach to design collaborative 3D interactions. Experimentations and evaluations are given and discussed in section five. The last section concludes the chapter and presents some future works.

2. Background and related work within collaborative 3D Interaction

In the literature there are two approaches to describe a collaborative 3D interaction. The first approach, allows a simultaneous action on an object by separating data (for example degrees of freedom: DoF) as rotations and translations to assign them to different users. In this approach, users can act together on the same object but when one user performs translations the other user does only rotations. Pinho and associates Pinho et al. (2002) classified this approach in two sub-categories:

– Homogeneous cooperative metaphors: users manipulate the object by using a unique single-user technique;

– Heterogeneous cooperative metaphors: in this case, users manipulate the object by using different single user techniques.

In the second approach, users have access to all available data (for example DoF). During manipulation the movement of the object is a combination of different movements of all users. Noma and associates Noma & Miyasato (1997) presented work on multiuser manipulation and interact with a shared object via haptic arms. Users are represented by simple virtual hands. The final movement of the object is the result of balance of forces applied by users. However, it may lead to inconsistency between virtual hand position and real hand. Indeed, when a user is going to apply a force to the object to move it, simple virtual hands of other participants attached to the object will also follow the moving object, which may seem inconsistent for users, because they have not activated their haptic arm.
A 3D cursor or SkeweR Duval et al. (2006) is another technique designed to keep the history of interaction and allow the correct representation of simultaneous interactions. It allows the simultaneous manipulation of an object by multiple users. Users control a 3D cursor that acts as a virtual simple hand, except that the selection is carried out automatically when approaching the shared object. If a user is available to manipulate the object, only rotations can be communicated to the object. If two users are available for the manipulation, the object is controlled as a ”rod” from the translation and rotation movements.
Duval Duval & Tenier (2004) have proposed a technique that derives from a RayCasting technique Bolt (1980) for manipulating object with two users. This technique is based on the following observation: if a user manipulates its ray to move a shared object, the ray of another user ”attached” to the same object will also move. However, the hand of the second user has not moved which creates a mismatch between the real movement and the virtual movement. Authors proposed to change direction of the ray in function of the force that is applied. They proposed three forms of rays (elastic, elbow or deformable).Another similar technique using a virtual ray (Bent Pick Ray technique) is also proposed by Riege and associates Riege et al. (2006).
More recently, the ”Three virtual hands” technique Aguerreche et al. (2009) which determines the motion (position and rotation) of an object from three points (position) associated to three virtual hand. In this technique only translations of virtual hands are taken into account.
Duval and associates Duval & Fleury (2009) proposed an asymmetric ”2d pointer /3d rays” technique for 3D interaction within CVE. The avatar is represented by a 3D object in the CVE but is controlled via a simple 2D pointing device (for example a mouse). This technique allows an asymmetric collaboration between a user immersed in a virtual reality platform

and another user using a simple PC.
Designing and using of collaborative 3D interaction techniques is not an easy task for developers and users respectively. Indeed, there are no mathematical models and formalisms for easy developing of generic and usable techniques yet. The design approach of most collaborative 3D interaction techniques (selection or manipulation) is considered as *local*. However, this design approach is focussed generally on how objects are to be selected or manipulated and often forget the principal players who are the users. It is necessary to consider a new design approach of collaborative 3D interaction from the *global* point of view by taking into account objects, 3D interaction tasks and users. Indeed a global approach to design collaborative 3D interaction techniques must take into account all of these parameters needed for interacting in CVE.
Therefore, it is necessary to find a way to manage and coordinate all these parameters to provide users with easy and intuitive interactions while enhancing the sensation of presence in a CVE. In the following section we present some fundamental concepts relevant to the management of group interactions in a CVE. These concepts are the basis of our contribution based on the design of a workflow for collaborative 3D interaction presented in section 4.

3. Managing interactions in CVEs

The best-known work performed for the management of interactions in the CVEs includes the spatial model of interactions proposed by Benford & Fahlen (1993). It was developed in the 1990s as a method of data transmission control in the CVEs. This model uses the properties of space as a basis to negotiate interactions and communications between communicating objects. The basic concept of this model is based on a breakdown of the virtual space. A metric space is defined and used to measure the positions and directions of different objects. From the position and orientation settings, objects have the ability to modify their interaction and communication. Objects interact with each other via a combination of media transmission such as audio, text or visual data through specific interfaces.
This model defines a set of interesting concepts such as the aura, the focus, the nimbus and the awareness. These concepts used separately or combined astutely can produce different interactions between objects in the virtual environment. In the following a brief presentation to these concepts is given:

– **Aura:** It represents an area in which an object can interact with another object. Objects are surrounded by their auras and move in the virtual world. When two auras are in collision the interaction becomes possible. Therefore, the aura may be considered as a fundamental interaction technology tool. The aura can take any shape or size. Typically, objects will bring up different auras (size, colour).
– **Focus:** It can be seen as a tool for direct attention and therefore filter information based on the boundaries delimited by the aura. It can be considered in some way as the user point of view.
– **Nimbus:** It represents a subspace in which an object makes many of its aspects available to other objects. These can be its presence, identity, activity, or a combination of these aspects. The Nimbus allows objects to draw attention of other objects to them.
– **Awareness:** It calculates the quality of interaction between two objects. The awareness calculation between two objects is not symmetrical (the awareness of an object A against the object B does not equal to awareness of B against A). This computation is performed by

using the focus and the nimbus. The awareness levels are calculated from a combination of nimbus and focus of the objects.

This model was subjected to numerous extensions during the years. We can cite the Sandor work with the AETHER system Sandor et al. (1997), the Greenhalgh work Greenhalgh (1997) and Greenhalgh & Benford (1999). In AETHER system, authors use focus, nimbus, and awareness concepts on semantic networks objects and relations. This allows building a history of objects and relations between objects that have been updated or deleted. Greenhalgh integrates "third-party objects" that provide support for contextual factors in awareness calculations and that enhance scalability. Third parties can have two effects on awareness: attenuation or amplification of existing awareness relationships, and the introduction of new aggregate awareness relationships.
The model of presence for cooperative applications Rodden (1996) represents an awareness model of interaction for multiuser applications. The main objective of the model of presence is to allow the sharing workspace of a cooperative application based on the notions of awareness and presence. This model is mainly based on the spatial model of interaction Benford & Fahlen (1993). The model of dynamic management of interests Ding & Zhu (2003) deals with the problem of presence management in collaborative virtual environments between different users. This model is focused on a dynamic interaction of environments. The model describes user's behaviours and more specifically the changes of their centre of interest over time.
More recently Bharadwaj et al. (2005) have proposed a model to ensure the awareness in heterogeneous environments, especially in environments with different interfaces. This model is based on the spatial interaction model discussed above. This model allows a user to have more focus to allow an easy choice of sources. Access rules are used to allow or reject certain sources.
An other recent model is proposed by Otmane and associates Otmane et al. (2007). This model is fully dedicated to collaborative 3D interaction. The authors have established a conceptual framework based on the functional aspect of 3D interaction (navigation, selection and manipulation) called "functional clover of 3D interaction". This model gives to users an ability to have knowledge about the system state and on the other hand provides information needed by the system to assist users to interact together. The navigation set contains functions for management of the user's position and orientation in the CVE. Selection and manipulation sets include respectively dedicated functions for selection and manipulation of an object or group of objects. This allows users to be aware of selections and manipulations that are performed in the CVE.

4. A workflow-based approach

In virtual reality the perception/cognition/action loop describes the relationship between a user and the virtual world (Fuchs et al. (2003)). We proposed to disrupt this loop by incorporating the concept of workflow (see figure 1). The workflow manages all the tasks to be performed and all actors involved in the collaboration process. Therefore it can be used on one hand for the coordination of 3D interaction tasks (navigation, selection and manipulation) and on the other hand for the communication of users in the CVE.
This functional framework allows users to have knowledge about the system state and other users activities: who navigates? who interacts? who communicates? who has difficulty?. On the other hand, the system must provide information to assist users to interact (easy selection, intend detection when moving towards an object) and communicate with others and more generally to work together.

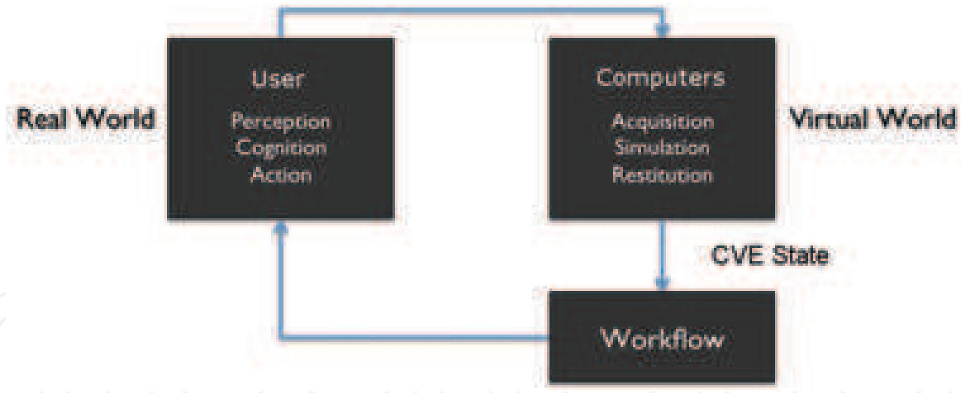


Fig. 1. Integrating the workflow in the perception/cognition/action loop

Workflow is a component ensuring coordination of users that can produce together (manipulate an object by several users, navigate, communicate, etc.). The proposed workflow consists of two components: a shared component and a motor component. The *shared component* represents the shared data space that symbolizes the behaviour of users and sources in the CVE. This component in someway can be considered as a collective memory in the CVE. This collective memory will give information about actions of the users. The second component of the workflow (*motor component*) represents the set of functions that deal with data processing from the shared space and provides tools to assist the users during the collaboration.

4.1 Shared component

The shared component consists of two state matrixes representing respectively the state of all users and all sources in the CVE. These two matrixes define the overall state of the system and are used to characterize the CVE at any time. The figure 2 illustrates this shared component. These state matrixes are constructed from information of users and sources. A *source* is an object that generates sensory information (virtual object and data media) that can be perceived by the users.

4.2 Motor component

The second component of the workflow corresponds to features dedicated to tasks and roles assignment during different interaction processes. It uses the shared data and applies them on *particular sources* in the CVE via *assistance functions*. Particular sources are objects that can be changed during the interaction process by different assistance functions dedicated to 3D interaction tasks. They act as a support tools for 3D interaction tasks coordination. Assistance functions are functions that help manage 3D interaction. They can act on particular sources to provide support to coordination.
The two following sections present particular sources and assistance functions used in the workflow motor component.

4.2.1 Particular sources

Particular sources are associated with functions that can be used by the motor component of the workflow to detect actions of the participants, or inform users about actions performed by other users in the CVE. Based on the spatial interaction model Benford & Fahlen (1993) and the functional clover of 3D interaction model Otmane et al. (2007). These particular sources are used to coordinate 3D interaction tasks in order to predict user’s interactions thanks to **aura,**

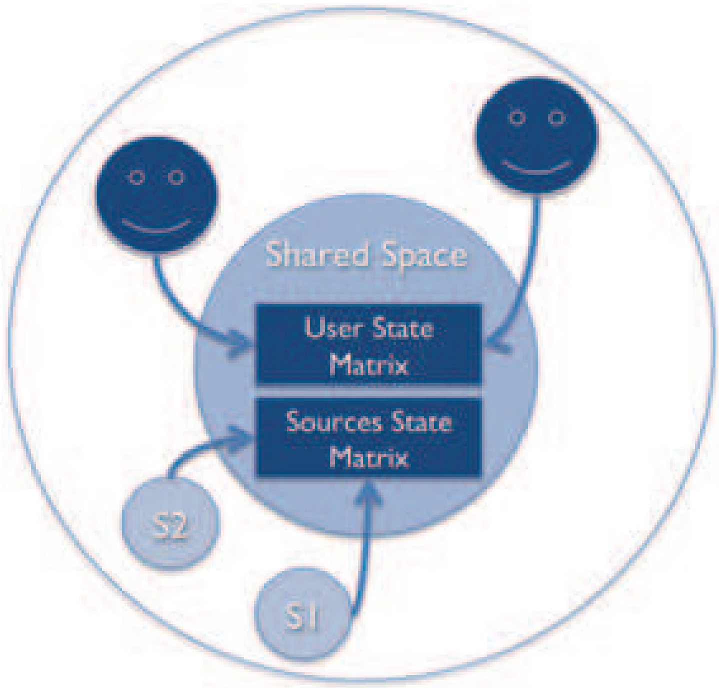


Fig. 2. Illustration of the shared component

focus and nimbus concepts. The coordination process is based on positions and orientations of the users in the CVE.

The workflow engine (motor component/space) receives information from the shared component that contains state vectors of users and sources. It acts on the aura, the focus and the nimbus to change the perception of users in the CVE (see figure 3).

Concretely we defined five particular sources: 3DIFocus, 3DIAura, 3DINimbus, 3DIAssistant and 3DIAvatar. Other sources are virtual objects in the virtual environment. These particular sources are used by the workflow, and they are exclusively dedicated to 3D interaction tasks.

- **3DIFocus:** This particular source corresponds to all other sources (virtual objects) with which the user can interact. They are sources that belong to the user's field of view. The intersection of two focus returns a common viewed sources of two users. This allows for example two users to interact on the same viewed sources. The 3DIFocus source can be considered as a tool for direct intention and will therefore enable filter sources that are not in the user's field of view. For example, the focus of $user3$ (see figure 3) corresponds to the source $S2$.
- **3DINimbus:** This particular source represents all users with the intention to interact on a single source. It represents the group of users who might select the source for possible manipulation in the future. For example the nimbus of the source $S1$ (see figure 3) represents the set $user1, user2$.
- **3DIAura:** It represents a 3D zone that surrounds a virtual object and allows single or multiuser selection. The selection is possible only if the avatars of users are in the aura of the source. This aura determines users who potentially want to select the source. This aura can also be used to surround the user's avatar in order to start conversations between users.
- **3DIAssistant:** This particular source enables a user to be assisted on specific actions that it performs. For example in the case of the selection of a source, the assistant can be activated

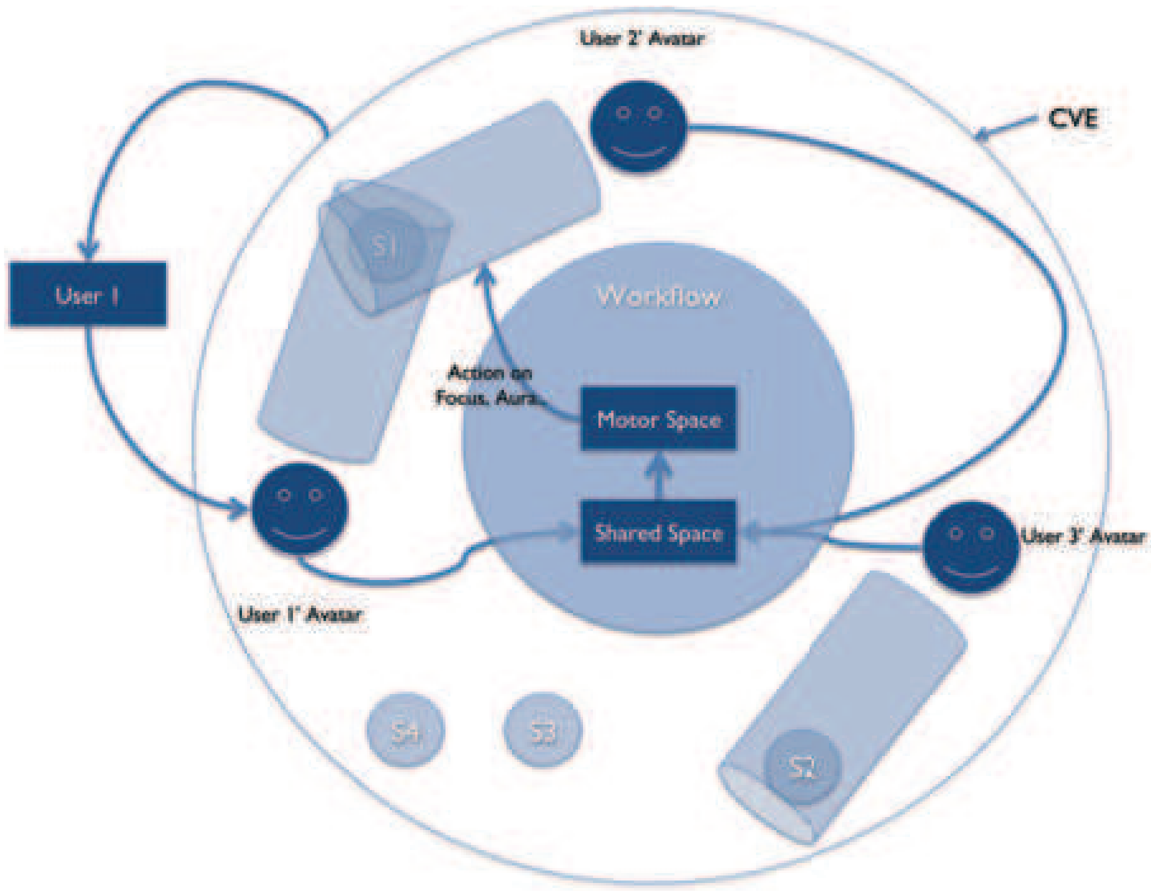


Fig. 3. Illustration of the workflow running in a CVE. Cylinders represent users focus and the nimbus of the source $S1$ represents a set of two users (user 1 and user 2)

as a multimodal (audio, visual and haptic) *virtual guide* Otmane et al. (2000), Ullah et al. (2009), Ullah et al. (2008) and Prada & Payandeh (2009). The assistant source as a virtual guide will enable an easier and precise selection of an object.

- **3DIAvatar:** The avatar source is a virtual representation of the user. It may take the form of a humanoid or a simple recognizable 3D object. It represents the position and orientation of the user in the collaborative virtual environment.

4.2.2 Assistance functions

Assistance functions are functions that operate on particular sources that can be used by the workflow engine. These functions operate with different 3D interaction tasks (navigation, selection and manipulation). By acting on these particular objects, the system is able to provide assistance to users and therefore coordinate their interactions in the CVE.

4.2.2.1 Navigation and selection functions

The navigation function will act on the aura colour using matrixes state data to indicate to the user his position towards the sources (see figure 4). This will inform the local user that he/she is close or away from the sources. For remote users, this function can for instance change the colour of the avatar of the other participants.
In our implementation example, the colour of the aura varies from red to green; red (see figure 5(a)) means a far distance while green (see figure 5(b)) means that the user is near the object.

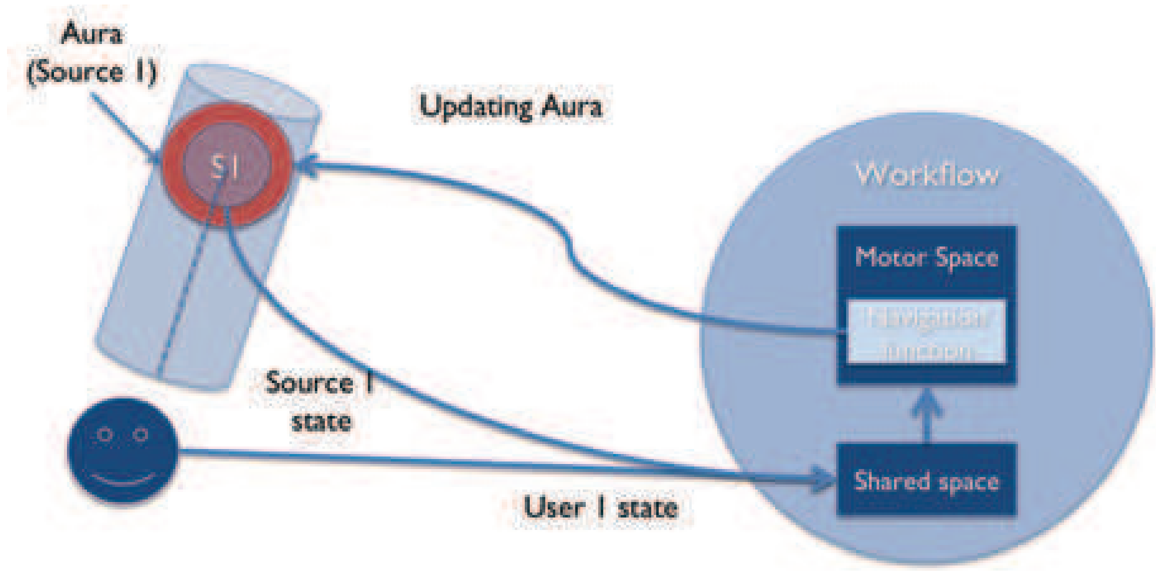
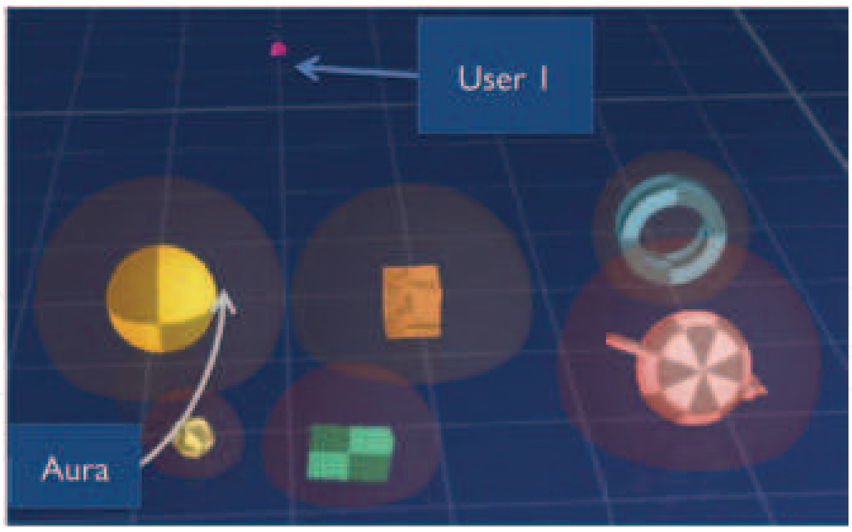


Fig. 4. The assistance function during the navigation task. In this example the navigation function updates the aura of the source $S1$ that is in the focus of the $user2$.

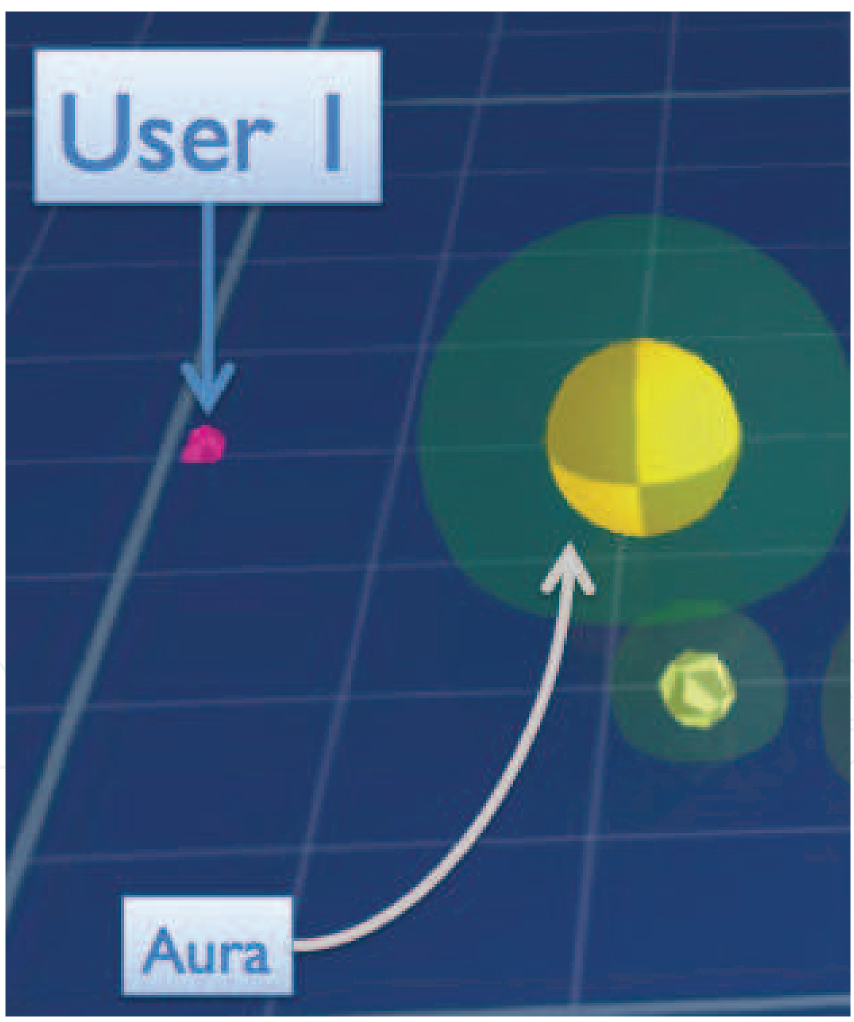
The user will see the changes of the aura colour depending on his movements.
The selection function is dedicated to manage selection of objects by the users. It becomes active when it enters the aura of the source. An assistant appears as a virtual guide (a cone which contains the user's avatar) to help the user in selecting the object (see figure 6). When the selection is validated, the manipulation may be possible.
The selection function acts on the colour of the virtual assistant (see figure 7). Once the user is in the aura of the object, the assistants (virtual guides) appear and guide the user towards the target (attachment point). The virtual guide colour modification is based on the distance between the user position (inside the assistant) and the object attachment point. This function gives the user the capability to know the position of his avatar to correctly validate the selection. Additionally, this function can act on the control of user interaction by prohibiting certain movements when the user's avatar belongs to the geometric shape of the assistant.

4.2.2.2 Manipulation function

As discussed in the related works, multiuser object manipulation is often limited to two users per object. In addition, dedicated techniques are usually proposed in multiuser manipulation making more laborious learning of users. Consequently, the transition from single-user to multiuser manipulation requires the change of technology and/or interaction technique. Indeed, if a user manipulates an object with a simple virtual hand technique, it is not conceivable that when a second user will select the same object, it needs to change his initial manipulation technique.
We want to allow multiuser manipulation of objects through any single-user interaction technique. In this way, the transition from the single-user to multi-user manipulation can be a natural and intuitive way. Indeed, this avoids the learning of a new metaphor and an additional cognitive load for users. Our approach is to integrate concepts of classical mechanics to modelling multiuser manipulation via a mechanical system composed by mechanical joints. In the following section we only presented the concepts of our multiuser manipulation. Technical details are not given in this chapter.



(a) The user is far from the sources, the aura is red



(b) The user is close to the sources, the aura is green

Fig. 5. Implementation example of the influence of the assistance function on the aura during the navigation task

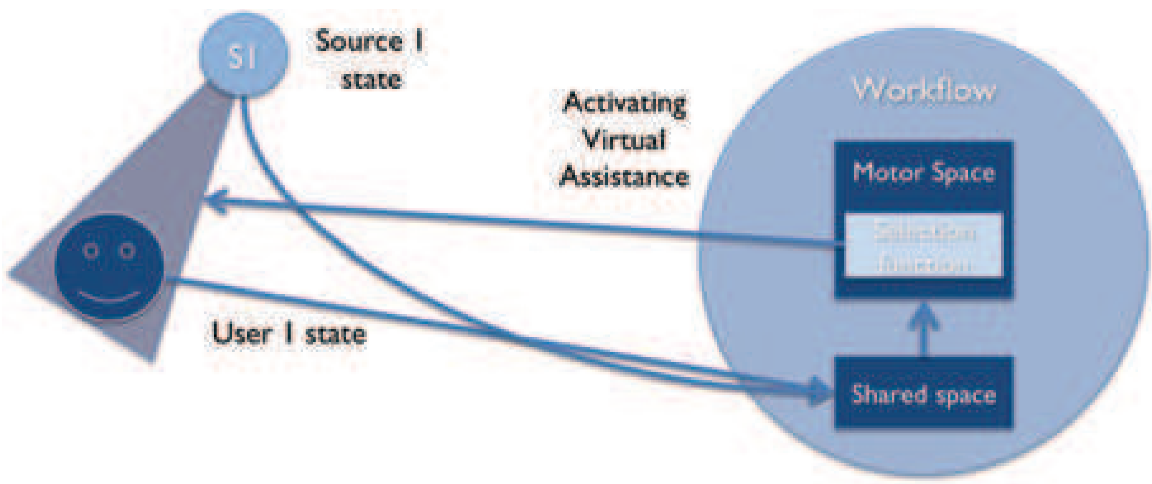


Fig. 6. The assistance function during the selection task. In this case the source $S1$ can be selected by the $user1$.

In the field of mechanics, a mechanism is the combination of several pieces, whereas in our case it will apply to multiple objects and avatars. These elements are linked together by contacts called mechanical joints. A mechanical joint is the description of the relationship between the different elements using mathematical models. When selecting an object via a single-user interaction, the avatar of the user becomes the "parent" item and therefore inherits the movements of the avatar. However, in the multiuser case, this principle may not apply.
For example, in the real world, when two users move a board, the resulting movement dependents on simultaneous users actions (users are related to the board by joints). We can model this by introducing virtual joints between avatars and objects (see figure 8). These joints will act as an *adapter* to allow a transition from single-user to multiuser manipulation.
In our case, joints between users and the object can be modelled by fixed or ball joint (see figure 9) links. This ball joint has three degrees of freedom on its three rotation components. Transmissible efforts will be on translation components.
To determine the object movement, we use forces that users perform on the attachment points of the object. The movement of the object is calculated from forces provided by users. In fact, by solving laws of dynamics relationship, we can determine accelerations in translation and rotation of the object. The figure 10 introduces the principle of the manipulation function when two users manipulate a source together. Figure 11(b) presents implementation of the

Fig. 7. Implementation example of influence of the assistance function on the assistant during the selection task.

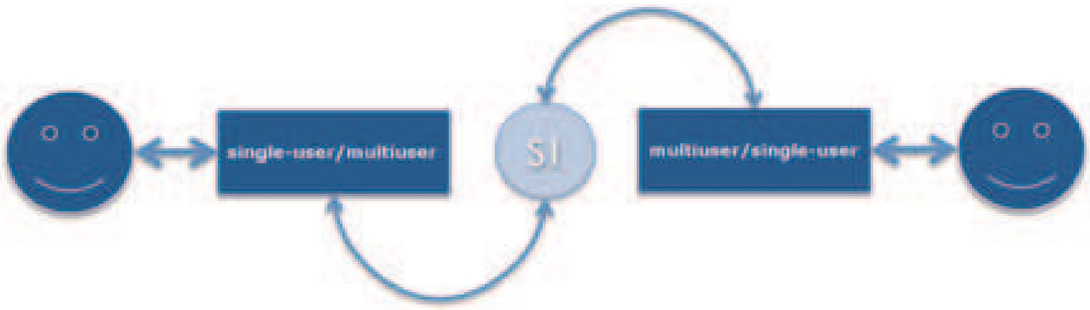


Fig. 8. Principle of our proposal to allow multiuser manipulation (adapters are represented between the user's avatar and the source).

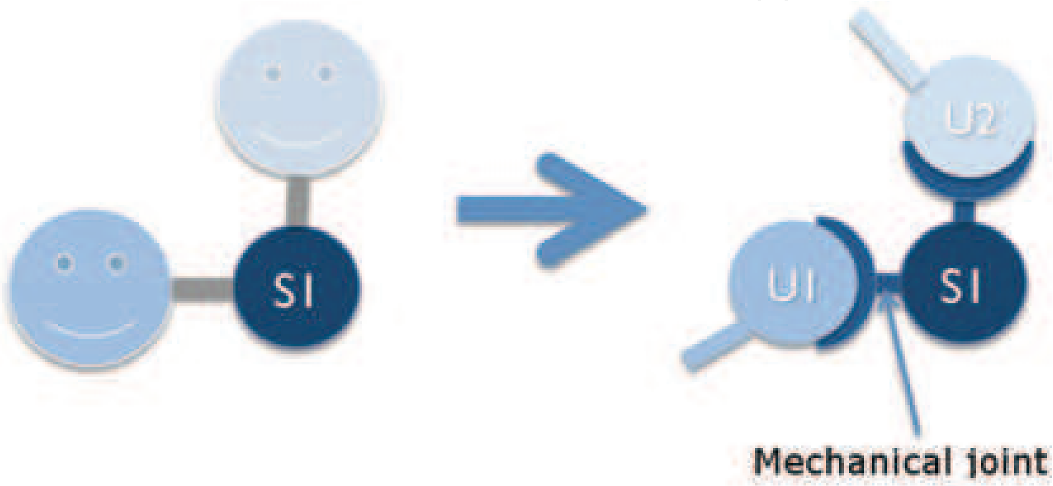


Fig. 9. Kinematic modelling of our cooperative manipulation problem.

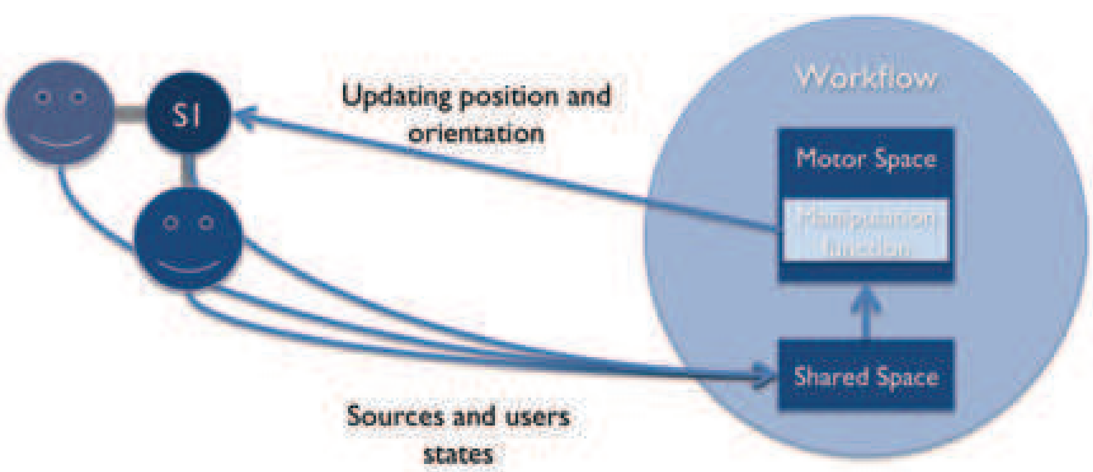
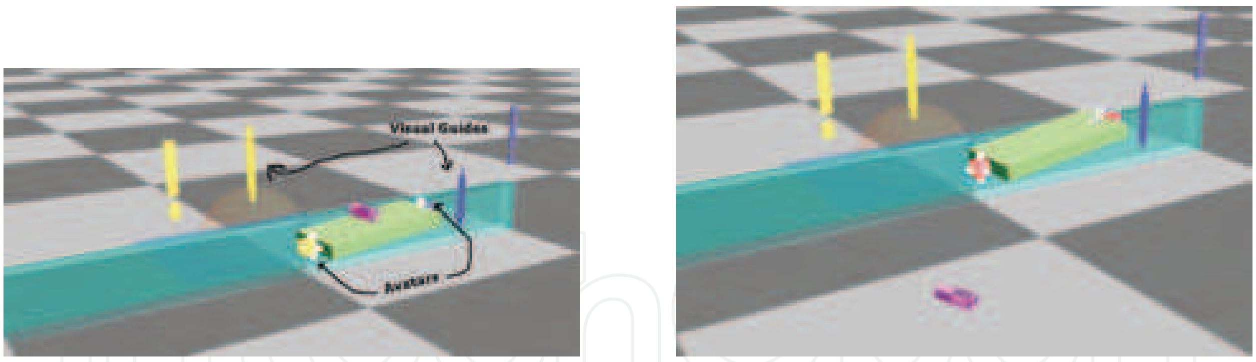


Fig. 10. The assistance function during the manipulation task. In this example a source $S1$ is manipulated by two users.

manipulation assistance function. In this case, the assistance function is activated (the colour of avatars become red).
During the manipulation of the object, the workflow system can also manage other virtual guides (see figure 11(a)) by displaying new directions to the users to enhance the coordination of the manipulation task.



(a) Displaying visual guides during multiuser manipulation

(b) Activation of the manipulation assistance function (avatars become red)

Fig. 11. The two kinds of assistance used to help the coordination of multiuser manipulation.

5. Experimentation and evaluation

In order to investigate the effect of the proposed workflow approach on human performance in a collaborative virtual environment, we developed two experiments. The first one is in a single user mode and tests the effect of assistance function on human performance during the navigation and selection tasks (activation and updating of the aura and the assistant sources). The second experiment is in a multiuser mode and investigates the effect of the manipulation assistance function (activation and updating of visual assistances and the command guide) on human performance during a manipulation task.
For these two experiments we used a human scale virtual reality platform (EVR@ platform[1] see figure 12. It is a large scale semi-immersive environment equipped with a retro-projected large screen (3m x 2.5m) for stereoscopic images, viewed with polarized glasses. In addition we have an ART optical tracking system with two Flysticks devices for 3D interaction.

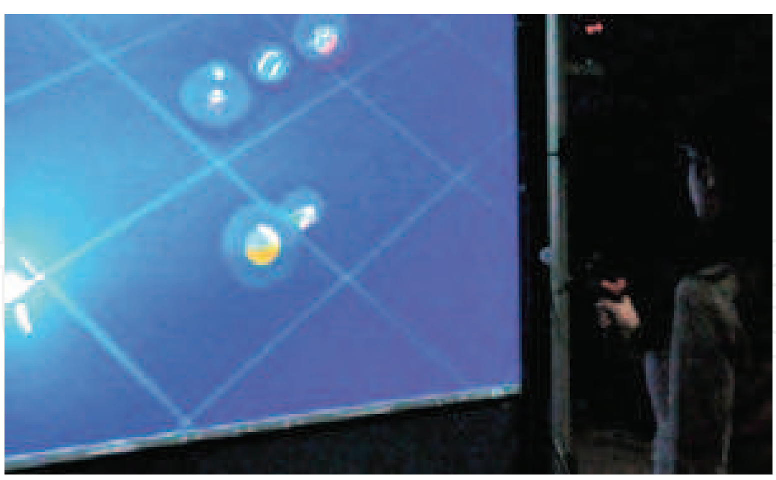


Fig. 12. The EVR@ platform with a user using a Flystick to interact in the virtual environment.

5.1 Experiment I

In this experiment the navigation and selection tasks were carried out in a single user setup. For this purpose one Flystick device and a simple virtual hand interaction technique were used.

[1] http://evra.ibisc.univ-evry.fr

Fig. 13. The virtual environment used to conduct the first experiment.

For this experiment we used a collaborative virtual environment as presented in the figure 13. It is composed of an avatar, and multiple objects (sphere, cube, cylinder, ring, etc.). These objects can be selected and are surrounded by their aura. All objects have the same colour. Users are represented by avatars with cylindrical shape. The colour of the aura varies as explained in the previous section and disappears when the user is inside (to do the selection). Virtual guides are conical shape and have a blue colour.
This experiment was performed by ten volunteers consisting of eight male and two female. Each subject was given a pre-trial along with a short briefing. Here the task for each user was to navigate in the virtual environment following the control points and to select the attachment point of the object cube (see figure 14). The test ends when the user validates the selection of the attachment point. In our model, the attachment points are points used to create mechanical joints described in the previous section that will allow users to manipulate a common object. They also specify the number of participants required for manipulating the selected object (in this case four users can manipulate the object)
For the objective evaluation, we test only the effect of the Selection Assistance Function (SAF) on the selection task performance, while the navigation assistance function is still activated during all the tests. Two conditions A and B are tested. In the Condition A (CA) the SAF is not activated (there is no assistance for the selection) and in the Condition B (CB) the SAF is activated (the selection is still assisted by the activated virtual guide). There were four trials under each condition and the evaluation is based on task completion time, errors and user's response collected through questionnaire.

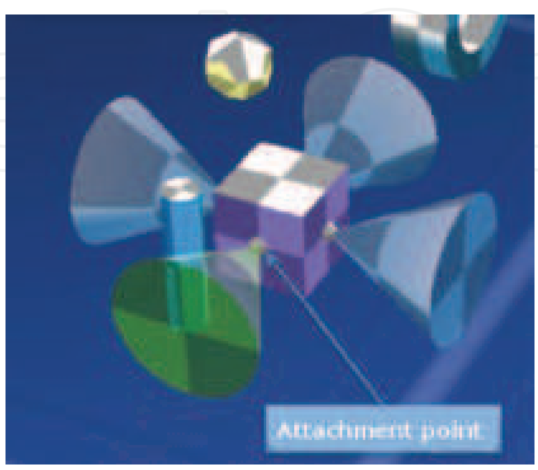


Fig. 14. Attachment points to reach with a simple virtual hand technique to validate the selection.

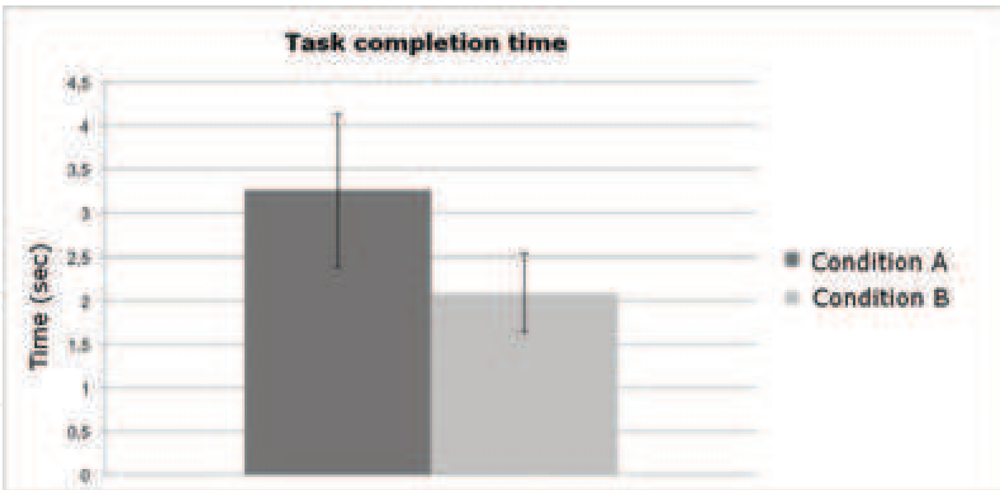


Fig. 15. Task completion time under conditions A and B in the selection task

5.1.1 Task completion time

Figure 15 illustrates the average task completion time for condition CA (SAF is not activated) and CB (SAF is activated) . For task completion time the ANOVA (F = 14,86, $p < 0.01$) is significant. Comparing the task completion time of CA and CB, we have 3.25 sec and 2 sec respectively with a significant ANOVA. This result shows that the SAF has an influence on task performance in the selection task.

5.1.2 Error in task completion

Figure 16 illustrates the average error rate for condition CA an CB. Here we present a global error analysis for each condition. For errors in task completion, the ANOVA (F= 4,69, $p < 0.01$) is significant. Tests without assistance (when SAF is not activated) have caused more errors (38%) opposing to tests with assistance (25% when the SAF is activated). The presence of errors made by the subjects is highly dependent on the conditions corresponding to the presence of virtual guides in the selection task.

These results are not surprising as the simple virtual hand technique is difficult to use when the object to select are small, which is the case here for cube attachment points. Virtual guides (in CA) improve significantly the perception of the distance between the avatar and the attachment point, which reduces both the selection error and the selection time comparing to the CB.

5.1.3 Subjective evaluation

For subjective evaluation users responded to the questionnaire after task completion. Here is a summarized result of the analysis of the answers. Users appreciate the presence of the particular source (aura) as well as the colours change according to the proximity of the avatar to the object. This allows users to have a better approach to reach objects.

However some users did not understand the purpose of the aura despite explanations before the beginning of the experience. Thus, for the question "*I think that I understand the role of the aura quickly?*", we got only 60% "*Yes*". Indeed, we saw that the use of the aura needs some user learning. However, we got 90% "*Yes*" and 10% of "*Probably Yes*" to the question "*Is the variation of the aura colours useful?*".

We found that changing colours of the aura helped users to move towards objects and to follow the given path. Users have therefore taken advantage of colours variation and the

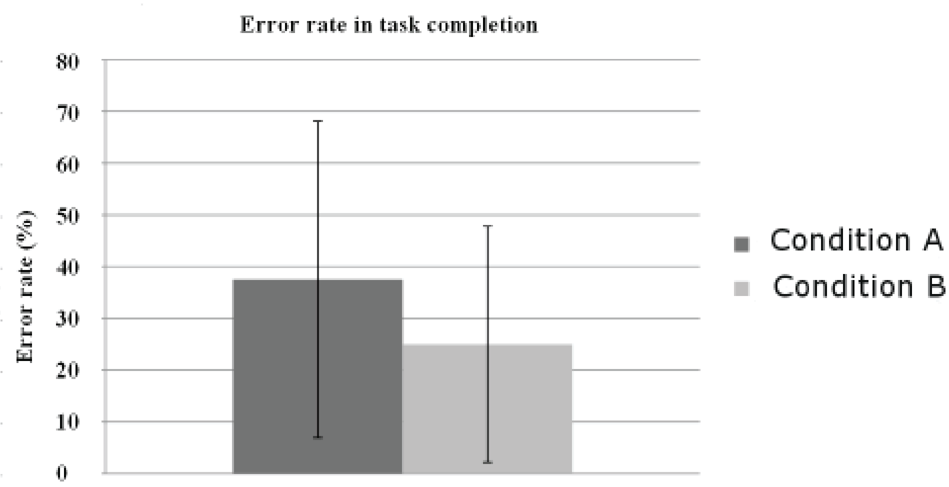


Fig. 16. Influence of the selection assistance function (SAF) on error rate during the selection task

assistance they provide. However, they did not necessarily understand the role of the aura. But, users have quickly understood the role of virtual guides in the selection phase and they found them very helpful and efficient.

5.2 Experiment II

The second experiment is dedicated to cooperative manipulation while in the first experiment the task was performed by users in a single user setup to achieve only navigation and selection. This multiuser experiment enables us to analyze the reaction of participants towards the use of our model and especially to study the influence of the Manipulation Assistance Function (MAF) on a performance of cooperative manipulation task.
In this experiment, a cooperative manipulation task was carried out with a couple of users. For this purpose two Flystick devices and a simple virtual hand interaction technique were used. Figure 17 illustrates this second experiment where two users manipulate a common object (a board) using two Flysticks.

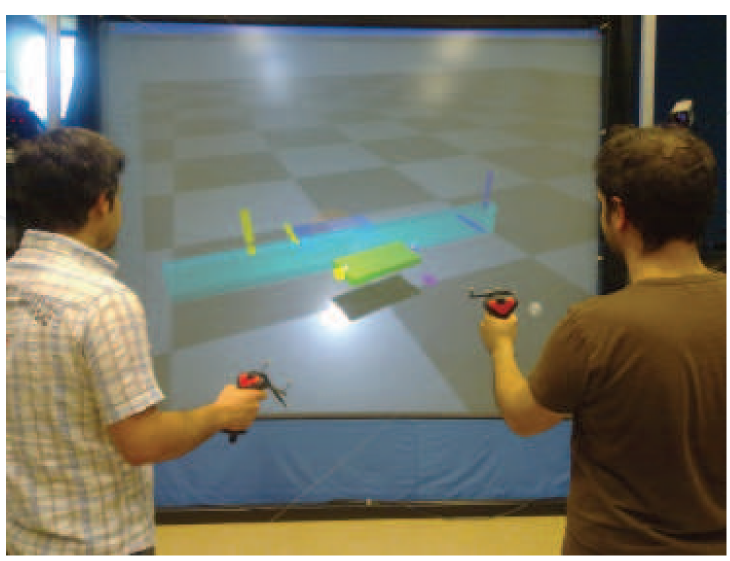


Fig. 17. The EVR@ platform where two users manipulate a virtual board via their Flysticks.

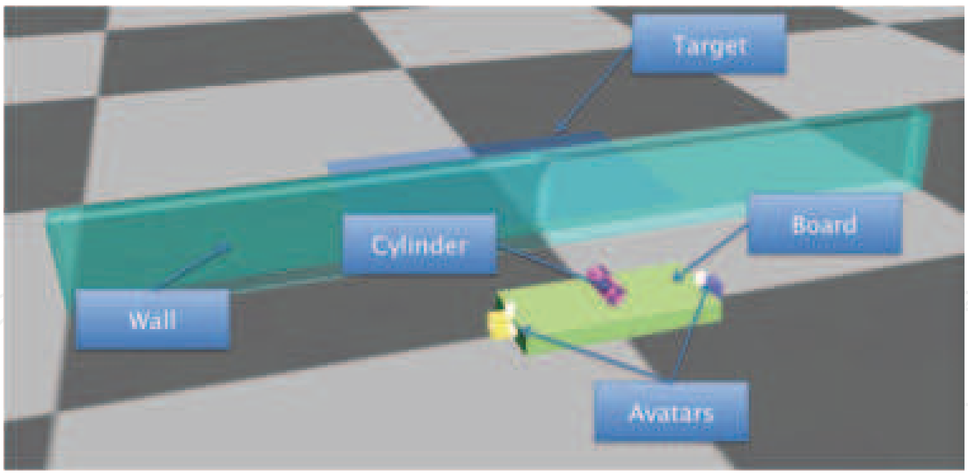


Fig. 18. The virtual environment used to conduct the second experiment

As in the first experiment, we have developed a simple collaborative virtual environment to focus on the study of the influence of the MAF on performance of a cooperative manipulation task. The aim is to compare the performances of multiuser manipulation task when the MTF is not activated (no assistance is given for coordination), partially (only visual aides are used) or fully activated (visual aides and manipulation control aides are used).
The collaborative virtual environment used for this second experiment is illustrated in the figure 18. This CVE consists of two avatars (for both users) and one board which support a free cylinder object. Users must move a board up to a drop area that will be used to validate the end of manipulation, avoiding the fall down of the cylinder that is setting above it. Two avatars (cubic shape) have the same size but with different colours. The yellow colour represents the first user, and the second user is in blue. The drop zone is in a blue colour. Access to the drop zone is located behind a wall.
User avatars are linked to the attachment points of the object board via a fixed (ceiling) mechanical joint (no degrees of freedom). This means that the avatar of each user is still fixed with the board (no translation and rotation are possible) between the avatar and the board as illustrated in figure 19.
This experiment was performed by twenty volunteers (ten couples) consisting of eighteen male and two females. Each couple was given a pre-trial along with a short briefing. For the objective evaluation, we tested the effect of the MAF (Manipulation Assistance Function) on the manipulation task performance. Three conditions A, B and C were tested. In the Condition A (CA) the MAF is not activated (there is no assistance at all), in the Condition B (CB) the MAF is partially activated (only visual aides are given during the manipulation). In the Condition C (CC) the MAF is fully activated (visual aides and manipulation control assistance are used).

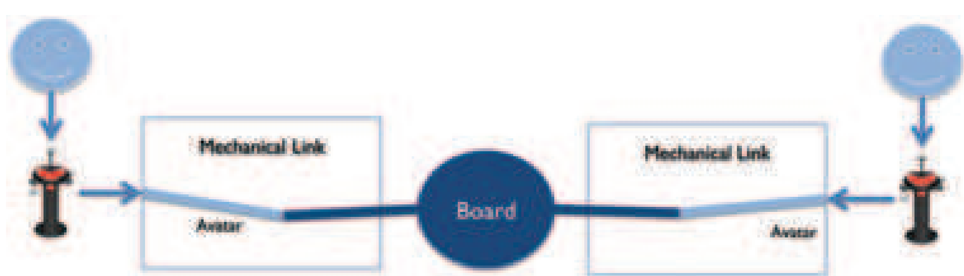


Fig. 19. Illustration of links between two user avatars and the board

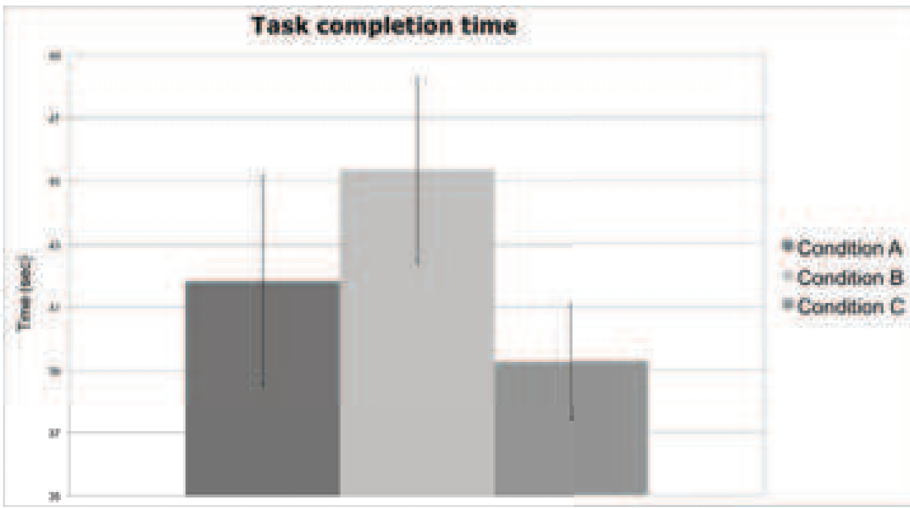


Fig. 20. Task completion time under various conditions in the multiuser manipulation task

There were two trials under each condition and the evaluation is based on task completion time, errors and user's response collected through questionnaires.

5.2.1 Task completion time

Figure 20 illustrates the average task completion time for CA, CB and CC conditions.
On average, tests on condition C are faster than those of the condition B. Indeed, visual assistances can certainly avoid falling objects while viewing how to correct the board movement more easily, but assistance is done at the expense of the manipulation time. Indeed, we observed that in the tests under the condition B when the visual aides appears (which means a future possible fall), users take more time to talk and discuss policy to correct and avoid falling, consequently they spend more time to achieve the task.
Without assistance (in condition A), users are not informed of a possible fall down of the cylinder and discover it only when it starts to roll on the board, which generally causes the fall of the cylinder. However, in the condition A, users do not stop working but try to avoid falling and communicate more.
This result shows that the MAF has an influence on a task performance in the cooperative manipulation setup. The full activation of the MAF (in the condition C) provides a best time performance (a mean of 39,2 sec) comparing to 45,2 sec and 41,4 sec in condition B (MAF is partially activated) and C (MAF is not activated) respectively.

5.2.2 Error in task completion

The CVE is decomposed into three sectors up to the drop zone (see figure 21). Sector 1 corresponds to the taking up step of the board; section 2 corresponds to horizontal movement of board to jump on top of the wall and the sector 3 corresponds to the go down step.
Figure 22 illustrates the error rate for CA, CB and CC conditions. The manipulation error rate corresponds to the average number of falls of cylinder of all users and for all tests.
Generally, we notice that when the MAF is activated, fully or partially (Conditions C and B respectively), thus may limit the number of falls. Indeed, the visual aid is a tool for anticipating the fails; it therefore allows users to correct their manipulation strategy. Besides adding correction movements (full assistance in CC) carried out by two users allows stabilizing the board to avoid as far as possible the fall of the cylinder.

5.2.3 Subjective evaluation

For subjective evaluation users responded to the questionnaire after task completion. Here is a summarized result of the analysis of the answers. Almost a ten couples users have found using the flystick is simple for the requested task (90% *"Yes"*, 5% *"Probably Yes"* and 5% *"No"*). The use of assistant tools doesn't cause additional difficulties for users. Indeed, visual guides are comprehensible for all subjects and are found to help much during the coordination (80% *"Yes"* and *"Probably Yes"* 20%).
Subjective analysis revealed us the preference of users for the condition C in which the two kinds of assistance are available (the MAF is fully activated). This mode of operation facilitates the board movement in sectors 1 and 3. However in sector 2, it produces cylinder falling (this requires a modification of the MFT to take into account the immediate stop of the board).
Concerning involvement and awareness aspects Gerhard et al. (2001), which give us information about the feeling of users during the experience; users were generally all involved during the experience, 90% responded *"Yes"* and 10% *"No"* to the question: *"Do you enjoy working with your partner?"*. This showed that users are involved in the common task. This makes sense because the experiment is quite fun and presents a challenge. For the question: *"I was a very active participant in the dialogue phases?"*, we obtained 80% *"Yes"* and 20% *"Probably Yes"*. This subjective result confirms the involvement of users in the task. However, it also highlights that users of the same couple have probably felt they were involved more than the other partner.

6. Conclusion

In this chapter, we presented a workflow-based approach to assist the coordination of 3D interactions in CVE. Principles as well as main concepts were presented and discussed. The goal was to provide a workflow system that helps users to interact together in a CVE. We highlighted the ability of the system to provide assistance to improve performances as well as in single-user interaction (to navigate and select) and in multiuser setup (in the case of more users manipulate the same object).
The proposed workflow consisted of two components: a shared component and a motor component (component engine). The shared component is presented as the shared data space that symbolizes the behaviour of users and sources in the CVE. The second component is presented as a set of assistance functions that deal with data processing from the shared space and provides tools to assist the users during the 3D interaction process. It uses the shared data

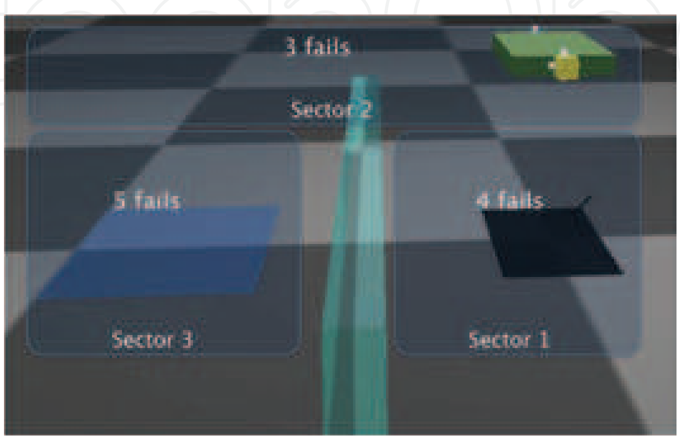


Fig. 21. Three sectors to determine the number of fails during the experiment II

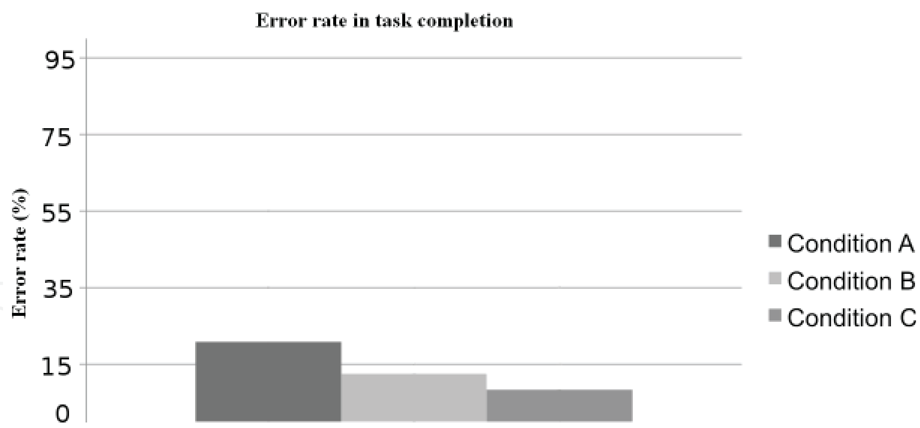


Fig. 22. Influence of the manipulation assistance function (MAF) on error rate during the cooperative manipulation task

and applies them via assistance functions (navigation, selection and manipulation functions) on particular sources (focus, aura, nimbus, assistant and avatar) in the CVE. Particular sources are objects that can be changed during the interaction process by different assistance functions dedicated to 3D interaction tasks. The proposed conceptual model can be used as a basis in many implementations and experimentation by developers of CVE.

In order to assess the relevance of our concept we have developed two CVEs and conducted two experiments. The first experiment (in the single-user setup) was intended to study the influence of the selection assistance function (SAF) when users navigate and select an object. The results are very encouraging because they showed that the presence of particular sources like aura and the assistant (when STF is activated) reduces significantly selection time and errors. The second experiment (with two users) studied the influence of the manipulation assistance function (MAF) when two users manipulate a common object. The obtained results were also encouraged because they highlight the importance of the presence of visual cues and manipulation control assistance (when MAF is fully activated).

Future work will be carried out to integrate the force feedback modality and examine its effects on cooperative task. Furthermore we will evaluate and implement the system on long distance network (i.e internet) and investigate the influence of network delay on it.

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Virtual Reality

Edited by Prof. Jae-Jin Kim

ISBN 978-953-307-518-1
Hard cover, 684 pages
Publisher InTech
Published online 08, December, 2010
Published in print edition December, 2010

Technological advancement in graphics and other human motion tracking hardware has promoted pushing "virtual reality" closer to "reality" and thus usage of virtual reality has been extended to various fields. The most typical fields for the application of virtual reality are medicine and engineering. The reviews in this book describe the latest virtual reality-related knowledge in these two fields such as: advanced human-computer interaction and virtual reality technologies, evaluation tools for cognition and behavior, medical and surgical treatment, neuroscience and neuro-rehabilitation, assistant tools for overcoming mental illnesses, educational and industrial uses In addition, the considerations for virtual worlds in human society are discussed. This book will serve as a state-of-the-art resource for researchers who are interested in developing a beneficial technology for human society.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Christophe Domingues, Frederic Davesne, Malik Mallem and Samir Otmane (2010). Collaborative 3D Interaction in Virtual Environments: a Workflow-based Approach, Virtual Reality, Prof. Jae-Jin Kim (Ed.), ISBN: 978-953-307-518-1, InTech, Available from: http://www.intechopen.com/books/virtual-reality/collaborative-3d-interaction-in-virtual-environments-a-workflow-based-approach

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51000 Rijeka, Croatia
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Phone: +86-21-62489820
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