Visuo-haptic Tool for Collaborative Adjustment of Selections

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Abstract. Mutual awareness between users working in collaborative virtual environments is an important factor for efficient collaborations. Several studies have reported that haptic feedback improves performance in collaborative tasks. However, few researches have tried to evaluate the influence of haptic feedback on mutual awareness, and to link the corresponding measures with the performance and efficiency factors. In the context of collaborative 3D polygonal modelling, we present a collaborative interaction method that dynamically adjust the selection area of the different involved partners. The aim of this interaction method is to improve the efficiency of collaborative working by improving the partners' mutual awareness. The experimental evaluation compares the proposed collaborative method of selection with a standard and individual method of selection used in most polygonal modelling software. The experimental results show an improvement in working efficiency and a better work distribution between the partners. Moreover, the analysis of awareness measure shows that the proposed approach balances self awareness and mutual awareness.

Keywords: Haptic feedback, polygonal modelling, shared situation awareness, selection adjustment.

1 Introduction

Distant collaboration is a promising solution to expedite team working and to associate experts with different skills in complex projects. However, this working approach presents a real challenge for the coordination of actions between the remote partners. In the case of the Collaborative Virtual Environments (CVE), the communication between partners is limited by the network latency, by issues related to the world consistency, and by the limits of communication systems which do not support some components such as gestural and facial expressions. All these issues limit the shared situation awareness (SSA), and may lead to a reduction of performance and efficiency of the group. Shared situation awareness (SSA) is the degree of similarity between each member's perception of a same given situation [1]. This component plays an important role in actions' coordination between partners and thus provides a better efficiency for collaborative tasks.

During the edition of the geometry of a shared object, a lack of SSA might produce unwanted deformations. For instance, when a first user manipulates a large selection and

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at the same time a second user manipulates a small selection overlapping the selection of the first user. If the first user didn't notice this second selection, it can conduct to unexpected deformations.

In fact, to complete reliable and effective collaborative tasks, the user needs to coordinate his actions and selections with the partner's actions and workspace. Thus, SSA plays an important role for collaboration in CVE.

Another issue for collaborative tasks concerns unbalanced workload between partners. This issue is due to social loafing and to the difference in skill level between partners. Social loafing corresponds to the tendency of the group members to do less than what they are capable of as individuals, the experiments of Blaskovich [2] suggest that social loafing is stronger in distant and virtually supported collaboration than in collocated collaboration. Unbalanced workload leads to a reduction in performance and efficiency during collaborative tasks.

In order to improve SSA during collaborative tasks, and to limit the unbalanced workload, we propose a collaborative method of selection which would force the user to pay attention to the partner's actions and workspace. This approach increases the user's attention to relevant information about the partner instead of providing additional information which may be useless [1]. Moreover, the proposed method integrates a haptic communication component that effectively communicate, through a visuo-haptic guidance, the required area to manipulate to the partner. The metaphor, named Collaborative Selection Adjustment (CSA), was experimented in the context of collaborative modelling. The investigated task concerns the manipulation of geometry of 3D polygonal models at different scales to produce new shapes.

2 Background

Several researches have investigated the role of the haptic channel in CVE. Sallnäs et al.[3], Basdogan et al.[4] and Groten et al. [5] have investigated the implicit haptic communication (i.e., feed-through) between partners during collaborative skill games applications. Their results have shown that haptic feedback significantly improves gestural accuracy and task performance. Groten et al. [5] have studied the influence of haptic feedback on efficiency (i.e., ratio between performance and physical effort). The results have shown that haptic feedback reduces working efficiency but improves performances. These studies highlight the importance of haptic communication during virtual collaboration. However, they focus on a standard haptic feed-through mechanism, which corresponds to the natural force interaction, and they do not investigate advanced communicative features of the haptic channel.

Oakley et al. [6] were among the first to use haptic feedback to create metaphoric communication. They have proposed different mechanisms of haptic communication to enhance interactions between partners during the collaborative edition of 2D diagrams. The cursors can attract or be attracted by each other, therefore the attraction mechanisms can indicate information about position. The subjective results have revealed that users find the haptic communication engaging and helpful. Girard et al.[7] have proposed an attraction mechanisms dedicated to 3D molecular modelling applications and they showed that the attraction mechanisms can be used to improve selection performances.

Ullah [8] has proposed several haptic interactions to improve the coordination during collaborative manipulations. The haptic functions enabled communication of the partner's actions. Moreover, they assisted the partners by keeping them in contact with the shared object. The different results have shown, through subjective measures, how haptic functions improved SSA and gestural coordination. The use of haptic channel to support metaphorical communication through artificial forces is well accepted by users. The proposed method was inspired by these metaphorical haptic communications to support team coordination.

Beyond haptic-centred approaches, Nova et al.[9] have investigated the link between the communicated information and SSA in the context of 3D video games. A visual awareness tool was proposed in order to provide different information to the partner. The results have shown that the awareness tool failed to improve SSA, but it increased performance. Endsley and Garland [1] noticed that providing more data is different from providing more information. Users can be overwhelmed by an excessive amount of data which may hide the useful information.

As introduced in a previous work [10], these two last works lead us to propose an interaction method which increases the user's attention on relevant information instead of providing additional information. The impact of the proposed collaborative interaction method on the SSA was measured by a Situation Awareness Global Assessment Technique (SAGAT) [11].

3 Proposed Approach

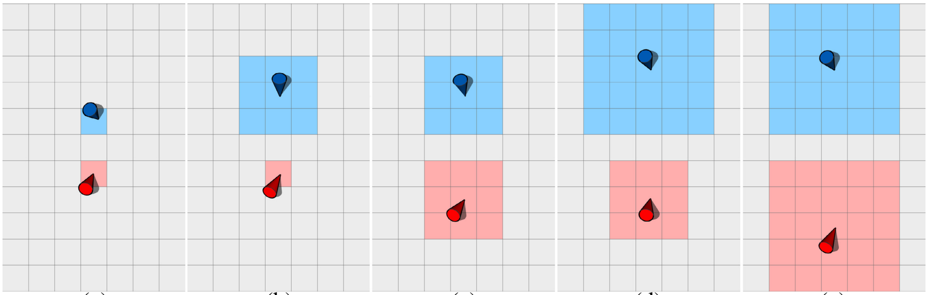
3.1 Context

In several fields, such as molecular modelling [12], virtual sculpting [13], and computer aided design [14], users need to have an access to different scales of manipulation. For example, during the molecular assembly, biologists need to manipulate the molecule from atoms (i.e., elementary structure), residues (i.e., intermediate structure), or fragments (i.e., important region of the molecule) in order to deform some local regions or the overall shape of the molecule for a good geometric matching with the second molecule during the assembly.

The study reported here investigates this issue in the context of multilevel manipulation of 3D polygon meshes. In fact, these geometric structures require manipulations at different scales such as a single face, a small group of faces, or an important part of the mesh in order to control the overall shape and the different levels of details of the designed object. The existing approaches to adjust the scale of manipulation consists in defining explicitly the required selection with a graphic user interface, for instance, with buttons or sliders to increase or decrease the size of the selection. However, this approach is not adapted for synchronous collaborative manipulations where users need to manipulate the shared object at the same scale. We propose to adapt this single user function to a collaborative function that involves two partners simultaneously.

3.2 Dynamic Adjustment of Selection

The proposed approach for collaborative adjustment of selection consists in dynamically adapting the areas selected by each user. More precisely, it increases or reduces



(a) (b) (c) (d) (e)

(a) One single face separate the two users, they both have a selection of one face. (b) Users are separated by 2 faces. (c) Users are separated by 3 faces. (d) Users are separated by 4 faces. (e) Users are separated by 5 faces.

Fig. 1. Size of the selection according the distance between the cursors

the selected areas (i.e., the number of selected faces) according to the distance (i.e., the number of faces) separating the two partners. The size of each user's selection area is determined by a propagation mechanism. From the faces touched by each user (i.e., faces in contact with the cursors), the selection areas are extended to adjacent faces which are connected by edges or vertices. In order to avoid overlapping between the two selection areas, which can lead to conflicting actions, the propagation is stopped before the two areas overlap. Thus, there is always at least one face between the two selected areas.

Figure 1 presents some cases of selections according to the distance separating the two cursors. On a flat surface with a uniform distribution of square faces (see Figure 1), the number of faces selected by each partner is defined by:

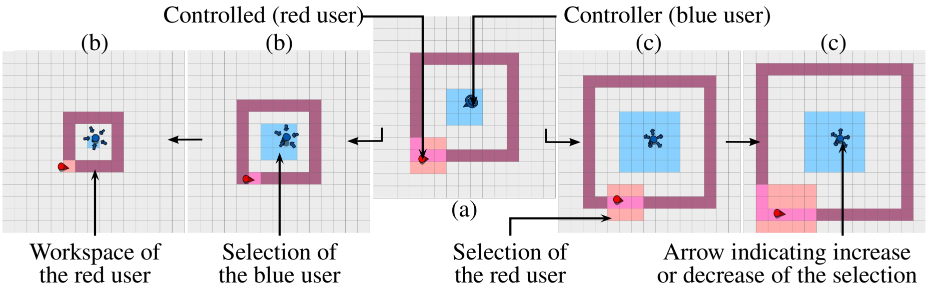
- $F_1 = (N + 1 - N(mod\ 2))^2$
- $F_2 = (N - 1 + N(mod\ 2)))^2$

Where N is the number of faces separating the users, F_i is the number of faces selected by the user i and $a(mod\ b)$ is the modulo operation of a by b.

With this selection method, partners just have to move closer or to move away in order to access to different scales of selections and manipulations. Thus, they can easily switch from a local manipulation to the manipulation of the overall mesh. This method generates two selection areas with similar sizes, thereby the partners always manipulate the mesh at the same scale. It should be noted that this function requires that both partners are simultaneously in contact with the mesh to adjust the selections, if only one user touch the mesh his selection is extended to the entire mesh. Once the selection completed, the two partners can manipulate independently their selections.

This approach is designed for collaborative tasks involving two partners. However, it can be extended to more users, for example, by taking into account the geometric distance with the nearest partner. Finally, the evaluation of this approach was limited in our study to the manipulation of planar shapes for an easier perception of the selection areas, and to avoid constraints related to the multiple points of view which are external to the current issue. However, the proposed approach can be applied to more complex shapes without any modification.

3.3 Control of the Selection Size



(a) Initial situation. The selection size is controlled by the blue user (controller user). The purple faces are the only faces where the controlled user (red cursor) can move. The controller user can not move away from the face he selects.
(b) The controller user reduces his selection size by bringing the controlled partner closer.
(c) The controller user increases his selection size by pushing the controlled partner away.

Fig. 2. Example of selection size control

The dynamic adjustment of selections allows the two partners to manipulate the shape at different scales. However, the partners need to coordinate their relative positions to obtain the correct selections and thereby perform the correct deformation. More precisely, once the first user selects a given face, the second partner have to select the correct relative position in order to get the correct size and position of selections to his partner. This involves the communication of the relative distance and orientation of the region to select to the partner. However, the designation of targets in 3D CVE is a complex and difficult task due to the limits of depth perception in 3D environments. To address this issue, we propose to provide the first user that starts the selection (named the controller user) with a communication tool that limits the workspace of the his partner (named controlled user). This workspace corresponds to the faces that respect the required distance between the two active selection. On a flat shape constituted by a homogeneous distribution of faces the limited workspace describes a square shape around the controller user. The movements of the controlled partner are haptically constrained on the limited workspace (Figure 2). The controller user controls the relative distance separating him from the controlled partner (i.e., the number of the faces separating the two cursors), and thus he can control the size of his selection. Inside this limited workspace, the controlled partner can move freely and thus can adapt his relative orientation according to the verbal indications of his partner. The controlled user can break the workspace limitation if he considers that the proposition of selection of his partner is incorrect or he can accept it and start the mesh deformation.

To increase (Figure 2.c) or reduce (Figure 2.b) the size of the active workspace (i.e., the radius of the faces separating the two cursors), the controller pushes or pulls on the face he is touching in order to push away or pull closer the active workspace. A haptic feedback imitates a press button effect to provide the perception of transitions.

4 Experimental Evaluation

4.1 Methods

The aim of this experiment is to evaluate the impact of the collaborative selection adjustment (CSA) on efficiency, workload balance and shared situation awareness. Based on these goals, we address the following hypotheses:
-**H1** CSA improves collaborative work's efficiency.
-**H2** CSA improves workload balance between users.
-**H3** CSA balances self situation awareness and shared situation awareness.

Hardware and Software Setup: The experimental platform was based on a standard desktop station. Two PHANToM Omnis from SensAble and two 23 inch screens were connected to the same computer in order to avoid network latency issues. The two working spaces were separated with a curtain to avoid visual contact between the partners. However, the participants could communicate verbally.

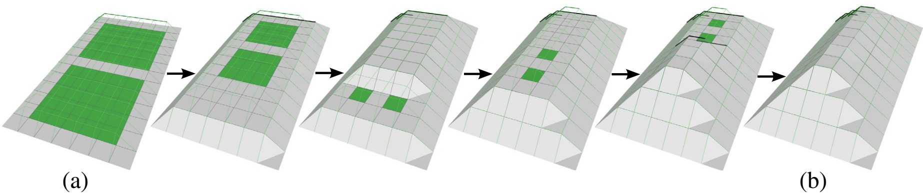


Fig. 3. Example of deformation task.(a)Initial 3d object: a plane. The two sets of green faces represent the faces the users have to select and translate. Only one user can see the green faces and knows the required selection. The green grid over the mesh represents the shape to match after the first pair of deformations.(b)Final 3d object after 5 sequential pairs of deformations correctly performed.

Conditions: Two conditions were presented to participants:
-**CSA:** collaborative selection adjustment
-**ISA:** individual selection adjustment
The CSA condition is based on the approach presented in this paper (cf. section 3.2). The ISA condition is based on the standard method of adjustment of the size selection used in computer graphics softwares. The selection size is controlled by a manual and individual method without interaction with the partner. The control of the selection size is based on the same interaction mechanism as the CSA approach. The user pushes or pulls the selected face to increase or decrease the size of his selection area (cf. section 3.3). Unlike the CSA method, the ISA condition does not constrain the position of the partner on an active workspace.

Participants: 24 participants (12 pairs, 21 men and 3 women) recruited in the LIMSI lab and University of Paris-Sud, aged between 22 and 34 years old, completed the experiment.

Procedure: The objective of the task is to deform a flat shape in order to turn it into new defined shapes: a pyramid (Figure 3), stairs and a canyon shape. The expected deformation is displayed with a green wire mesh (Figure 3.a) and five pairs of deformation are required to succeed. The correct selection to perform the required deformation is displayed with two sets of green faces (Figure 3.a). The required deformation (green wires) is displayed for both users, but the required selections (set of green faces) are only displayed for one single user. This additional information, provided to one user, is important to create an unbalanced knowledge and to force communication between the partners. Every selection indication (green faces) is presented in pairs, in order to encourage parallel work.

The subjects follow a progressive tutorial before performing the evaluated task. Furthermore, in order to simplify deformation tasks, the deformations are constrained according to the normal vector of the manipulated face.

Measures: Several objective measures were collected for both conditions. The following measures concern the evaluation of performance and efficiency.
- **M1** Completion score (%): mean percentage of successful deformations.
- **M2** Completion time (s): mean time to perform all the required deformations.
- **M3** Travelled distance (dm): average distance travelled by both users during the task.
- **M4** Deformation distance (dm): average distance travelled by both users during the deformations process.

The following measures concern the analysis of the work distribution within pairs:
- **M5** Distance difference (dm): difference between the distance travelled by each of the two users (| M3 of user 1 - M3 of user 2|).
- **M6** Deformation difference (dm): difference between the distance travelled by each of the two users during the deformations (|M4 of user 1 - M4 of user 2|).

Finally, the following measures are proposed to study the evolution of situation awareness (SA) and shared situation awareness (SSA). During each modelling task, the interactions with the 3D object are frozen at a random instant. The cursor of the partner is removed from the visual display. The indications of selection (green areas) are also hidden. Then, we ask participants to indicate the following information:
- **M7** Next selection (SA): What will be your next selection?
- **M8** Partner's next selection (SSA): What will be your partner's next selection?

For these two measures the participants have to indicate the planned next selection by touching the corresponding face. This measure provides a binary value; 1 means the user guesses correctly the next selection performed, 0 means the user did not find the next selection.

Subjective Measures: A questionnaire composed of 3 statements was presented to each participant after each condition. The subjects indicate on a Likert-scale if they agree or disagree with the statements. Scores ranging from 1 to 5 mean strongly disagree and strongly agree respectively.
- **S1** The tutorial was not necessary.
- **S2** I have done the same number of deformations as my partner.
- **S3** The work was evenly distributed between me and my partner.

4.2 Results

As our population does not respect a normal distribution, we used a non-parametric statistical test named Wilcoxon signed-rank test to determine if the results are significant.

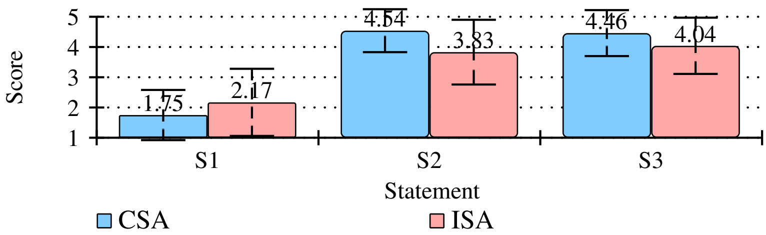


Fig. 4. Subjective results and standard deviation

Table 1. Results for the efficiency measures and for the distribution measures

	M1(%) Completion score	M2 (s) Completion time	M3 (dm) Distance travelled	M4 (dm) Deformation distance	M5(dm) Distance difference	M6 (dm) Deformation difference
ISA condition	69.9	125	372	21.4	55.55	7.99
CSA condition	77.4	113	284	19.1	51.32	3.78
Reduction (%)	-10.7	9.5	23.7	10.6	7.61	52.7
Wilcoxon (p-value)	0.295	0.063	0.001	0.658	0.278	0.035

Work Efficiency: Table 1 summarizes the results related to the completion score (M1) and completion time (M2). The mean completion score presents a non significant improvement of 10.7% from ISA to CSA ($p - value > 0.05$). However, the completion time is reduced by 9.5% with a borderline p-value ($p - value < 0.1$). The improvement in performance under the CSA condition is arguable. We can consider that the performances under the two conditions are similar. The score of **S1** (Figure 4) suggests that the ISA condition is easier to understand than the CSA condition. Users are indeed faster with the ISA condition which may improve the performance at the beginning of the experiment.

The analysis of the travelled distance (M3) shows a significant reduction of 23.7% between the ISA and CSA conditions ($p - value < 0.05$). Under the CSA condition, users are more careful about their movements since they influence the selection of their partner. This leads to a reduction of the travelled distance. The efficiency is defined as the capacity to produce outcome with minimum effort, so we can consider that CSA improves working efficiency since the effort is reduced without affecting performance. Thus, hypothesis **H1** is validated. By contrast, the deformation distance measure (M4) shows no-significant difference ($p - value > 0.05$) between the ISA and CSA conditions. CSA reduces the effort involved during the overall task but not the effort involved during the deformation process.

Work Distribution: Table 1 presents the results related to the difference of travelled distance (M5) and deformation distance (M6). These results show a non significant improvement in the difference of travelled distance of 7.61 % ($p - value > 0.05$) between the ISA and CSA conditions. The two partners travelled similar distances.

By contrast, the deformation difference (M6) measure shows a significant reduction of 52.7 % ($p - value < 0.05$) between the ISA and CSA conditions. Indeed, some users are more efficient than their partners. They may have better skills in 3D environments and haptic interaction. CSA reduces this difference because the two partners have to work simultaneously in order to deform the mesh. Under the ISA condition, the two partners can work independently, which can lead to an unbalanced activity. If one participant is far more efficient than his partner, he can individually perform all the tasks. The statements **S2** and **S3** of Figure 4 concern the perception of the work distribution. The scores of **S2** and **S3** (Figure 4), corresponding to the perception of the work distribution, are more important for the CSA condition (0.71 and 0.42 respectively) than for the ISA condition. This subjective result suggests that users perceived a better balance of work distribution under the CSA condition. Thus, hypothesis **H2** is validated.

SA and SSA: Table 2 compares the M7 measure (SA) with the M8 measure (SSA) according to the ISA and CSA conditions. Under the ISA condition, the M7 measure is significantly more important ($p-value < 0.05$) than the M8 measure. This result shows that users are more accurate and aware of the selection that they plans to do (SA), than of the selections planned by their partner (SSA). This difference between shared and self awareness is not observed under the CSA condition. Compared to the ISA condition, CSA does not improve self situation awareness (SA), however CSA improves the balance between situation awareness (SA) and shared situation awareness (SSA), the hypothesis **H3** is thus validated. The user's awareness is better shared between his activity and the activity of his partner. This results suggest that awareness capacities are limited, and that in this application context awareness can not be increase but they are rather redistributed.

Table 2. Comparison of results between M7 and M8 measures

	ISA condition	CSA condtion
M7 Next selection	0.69	0.61
M8 Partner next selection	0.44	0.55
Reduction (%)	36	9.1
Wilcoxon (p-value)	0.014	0.53

5 Discussion and Conclusion

The experimental results confirm that haptic feedback improves working performance during collaborative tasks [4] [3] [5]. Moreover, in contrast to the results of Groten et al.[5], the proposed approach improves working efficiency. The differences in context (i.e., 2D skill games) and metrics used (i.e., force and velocity) may explain this difference in the obtained results. The collaborative method of selection balances the situation awareness and the shared situation awareness which can be useful for a more efficient supervision of the collaborative process. We experimented our approach with simple modelling tasks which were especially designed to be suitable for collaborative work. It would be interesting to evaluate this same approach with a more generic and complex modelling tasks. Moreover, the investigation of new contexts like virtual sculpting [13] could highlight new constraints requiring some adaptation such as new criterion to adjust the selection areas (e.g., euclidean distance between cursors instead of a number of face).

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