2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)
Banff Center, Banff, Canada, October 5-8, 2017

Usage of Tactile Feedback to Assist Cooperative Object Manipulations in Virtual Environments

Thomas Volpato de Oliveira
thomasvdeoliveira@gmail.com

Márcio Sarroglia Pinho
pinho@pucrs.br

Virtual Reality Group – PUCRS, Brazil

Abstract— **This study evaluates the usage of tactile feedback to aid cooperative object manipulation using the SkeweR technique. This technique is based on the use of crushing points, where the users grab the object for the first time, to simultaneously move/rotate an object. Once the user keeps his hand positioned on the crushing point, during the object manipulation, the interaction becomes more natural, in the sense that it is more similar to the real process. However, due to the lack of any physical constraint to the users' movements, it is often noticed that the user's hand moves apart from the crushing point during the interaction. To solve this problem, this work proposes the usage of tactile feedback to inform the user about the distance of his hand from the crushing point. The tactile feedback is provided by a vibration micromotor attached to the users' thumb. To validate our method, we ran a user study based on the 3D manipulation of a virtual object, which has to be translated and rotated through a virtual path along a virtual wire, from the beginning to the end of it. During the interaction, users manipulate a 3DOF position tracker and should keep this tracker at the same position of the crushing point. During the trials, the participants used three modalities of interaction: without any feedback, with a visual feedback and with tactile feedback. Results showed that the users kept the tracker closer to the crushing point when using tactile feedback.**

Keywords—Tactile Feedback; 3D Interaction; Tracking

I. Introduction

Virtual Reality (VR) technology allows users to visualize and interact with three dimensional virtual spaces in real time. It can be applied on several areas, such as training, simulation, entertainment and visualization. In the last, it is interesting that multiple users interact with the scientific data collaboratively, thus increasing their involvement and understanding of the data analysis [1]. Additionally, the multi-user approach can be helpful in tasks that that are difficult for a single user to perform [2].

Collaborative manipulation refers to the simultaneous manipulation of virtual objects by multiple users [2] [3]. It can be helpful in complex situations that are too hard for a single user to perform efficiently, such as an obstacle preventing the user from visualizing the manipulated object, requiring him to navigate in order to complete a manipulation. A second user, positioned at a different viewpoint, can help the first user to manipulate the object in a timely fashion [2].

There are multiple ways of defining how the manipulation from each user will be combined to create a single output. Some approaches separate the control each user has over degrees of freedom (translation and rotation operations) [2] [4] [5]. Others separate the degrees of freedom but define some motion restriction points [6]. Finally, a translation can be applied alone by each user, being composed into the virtual object position and orientation, as the SkeweR technique [7].

Sight is the primary sense relied upon by users when interacting with virtual environments. Other senses such as touch and hearing can be explored to provide additional feedback. Even though a collaborative manipulation of objects based only on visual feedback is often used, it is not always the best option to transmit information. In the real world, the forces transmitted from one user to another, through the shared object, are fundamental for human interactions. In virtual environments based only on sight, the absence of haptic feedback during human interaction can be less effective.

In this context, this work aims to evaluate how the use of a haptic feedback can help the users to perform a more natural and precise collaboration. As a test bed, we choose the SkeweR interaction technique [7].

When using this technique, each user grabs the object by one **crushing point (CP)** to start the collaborative interaction, like when handling the extremity of a skewer. During this interaction, while each user is moving his hand, a new position and orientation is computed for the shared object, based on the positions of each users' hands. Since there is no device that prevents the users from moving their hand off the crushing points, as the distance between the crushing point and the users' hand grows, interaction becomes more unnatural. Fig. 1 shows some scenarios which could happen during the collaborative interaction.

Based on this premise, this work proposes to design, implement and evaluate mechanisms to alert the user that he is moving his hand far from the crushing point, allowing him to return the pointer to a more natural position. Visual and haptic feedbacks were used to alert the user.

This paper is organized as follows: in Section 2, some related work that uses haptic feedback during interaction, to improve the user experience, is described. Then Section 3 presents how the real and virtual setups were modeled for the trials and how the three modalities of feedback were generated and used. Then, Section 4 presents how the experiment was conducted. After that, the objective and subjective results of the experiment are presented in Section 5, with conclusions and future work in Section 6.

II. The Usage of Haptic Feedback During Interaction

Some works [8] [9] [10] use vibration motors to inform collision in a virtual environment. Bloomfield et al. [8], for example, uses different intensity levels of vibration to inform how much of a virtual object is inside another during a collision.

Some of these studies use a simplified collision feedback in order to guide the user while interacting with an object. In the work of An et al. [9], for instance, a vibration motor is placed on the user's arm to notify when it is necessary to apply more force on a virtual object to move it, or less force to prevent it from breaking. The amount of force applied over an object is informed based on the linear variation of the motor's vibration. Similarly, Walker et al. [10] uses vibration motors to inform the user when it is necessary to apply more force on an object to prevent it from falling. In this work, the intensity of the vibration motors is linearly proportional to the falling acceleration of the object.

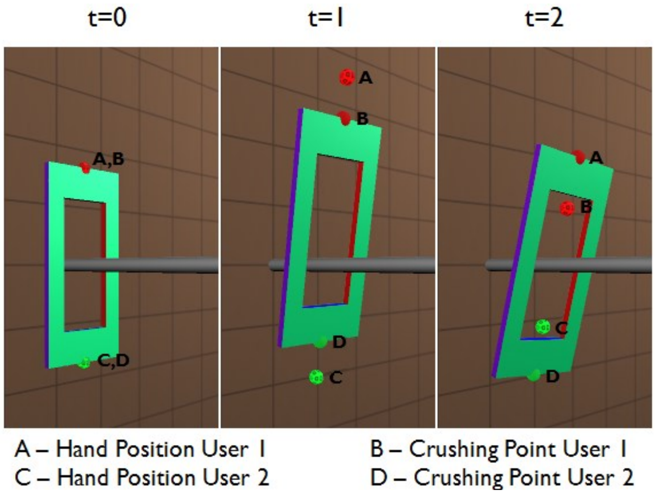

Fig. 1. Differences between crushing points and real hands positions over the time t.

Besides active tactile feedback, Salzmann et al [11] and Aguerreche et al [12] used passive haptic feedback to convey information for collaborative interaction. Salzmann investigates two different types of interaction in an assembly task, in which two users had to move an object in a virtual environment. Once both users had caught the virtual object, its position and orientation were calculated by the average of the users' hand position and orientation. During the test, the first interaction was solely based on visual feedback. As the users had no movement restriction or haptic feedback, they could experience difficulties to understand some actions from their partners, such as lifting the shared virtual object. The second interaction applied a passive haptic feedback to limit the users' movements, forcing them to hold a real-world handle that mimics de position where the users had to catch the virtual object in the virtual environment (Fig. 2 (a)). By using this handle, when a user moves his arm, his partner easily perceives the action. The study indicates that the trials with passive haptic feedback were the most efficient regarding both task completion time and precision.

Aguerreche et al, also used a passive haptic feedback to improve virtual object manipulation, however, they used a reconfigurable tangible device (RTD) that could be adapted to roughly match the shape of a virtual object (Fig. 2 (b)). This device has handles that could be compressed or stretched to form the representation of a virtual object. Compared with two other techniques (the Mean Technique [13] and Separation of Degree of Freedom technique [13] [2]), the tests revealed that RTD has a significant effect on the realism, training, and presence. However, it did not show a significant effect on fatigue neither on how much the users enjoyed the technique.

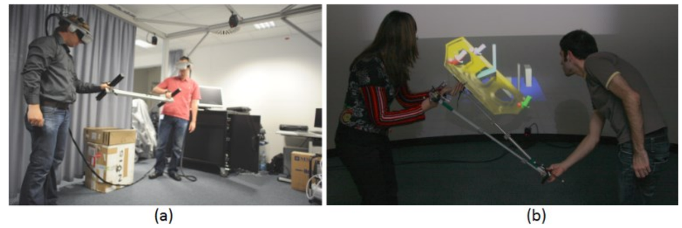

Fig. 2. Technique examples. Image sources: (a) [11] and (b) [12].

III. Experiment

The experiment consists of a simple task where two users have to manipulate together a virtual object by translating and rotating it through a virtual wire course.

As aforementioned, during the interaction process, using the SkeweR technique [7]. This technique generates the position P_O and orientation R of the shared object as follows:

$$P_O = \frac{1}{2}\,(Pc_1 + Pc_2) - R\,\frac{1}{2}\left(\frac{Pc_1}{P_O} + \frac{Pc_2}{P_O}\right)$$

$$\vec{v} = \overrightarrow{Pc_1 Pc_2}$$

$$\theta = \tanh^{-1}\left(\frac{\vec{v_t}\cdot\vec{v_{t+1}}}{\|\vec{v_t}\| \times \|\vec{v_{t+1}}\|}\right)$$

$$\vec{\omega} = \vec{v_t} \wedge \vec{v_{t+1}}$$

P_O = Object Position
P_{C1} = Crushing Point 1
P_{C2} = Crushing Point 2
V_t = V on time t
V_{t+1} = V on time t+1
θ = rotation angle for shared object
ω = rotation axis for shared object
Λ = cross product
R = quaternion generated by ω and θ.

Due to the lack of any physical constraint, the hand position can be moved apart from the initial position of the crushing point. So, after grabbing the object, the users are asked to keep the pointer as close as possible to the position of the crushing point on the object's surface. In order to help the users in this task, we apply three different approaches: visual feedback, tactile feedback, and no feedback.

During the experiment, each user was seated in the opposite side of a table while holding a magnetic tracking device, which has 3DOF for translation, in his dominant hand. Each user had a 23" LCD screen to visualize the virtual environment in a first-person viewpoint. Fig. 3 shows the real setup.

The virtual environment for this task (Fig. 4) consisted in a small 3D area above a desk, displaying a wire course in the middle. During the task, the users had to move a virtual squared ring along the wire, while avoiding to touch the wire. The starting point of this ring was always in one side of the wire course, with the virtual object placed in a position free of collisions. In addition, along the wire course, there were some obstacles to be avoided, which forced the users to rotate the virtual object. Each user was looking to the wire course from the opposite side of the box as they were in the real-world setup.

A straight wire was used, as the results of preliminary tests revealed that the use of a complex wire confused the users about the depth of the environment due to a monoscopic screen.

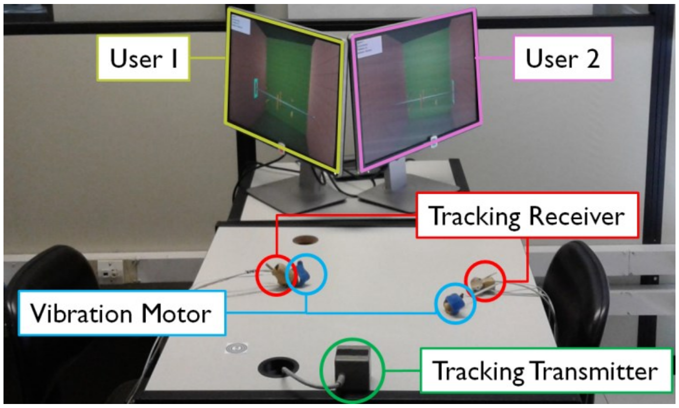

Fig. 3. Real Experimental Setup.

In the virtual environment, the hand of each user is represented by a virtual sphere used to select the crushing point from where the user wants to move the object. The object selections were performed by pressing a button attached to the tracker. Once both users had grabbed the virtual object, they could move it to the other side of the wire (destination). As soon as the object reached the destination, the object position/orientation was reset to the initial position/orientation and a new trial began.

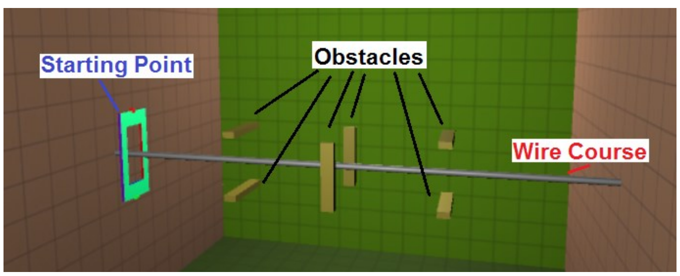

Fig. 4. Virtual Environment used in the experiment.

A. *Feedback Modalities*

After the object selection, a small sphere on the virtual object's surface indicates the original crushing point for each user, as Fig. 1 (b and c) shows. For each user, a different color is assigned to his sphere.

In order to help the user to keep his hand near the original crushing point, three different warning modalities were tested. The first generates **no feedback (NF)**. The second uses **Visual Feedback (VF)**, which shows a line between the initial crushing position and current user's hand position. Additionally, the latter blinks (Fig. 5).

The third approach, the **Tactile Feedback (TF)**, produces vibrations on the user's hand as long as the current tracker position and original crushing position are different. The vibration intensity (amplitude) is linearly proportional to the distance between these two points. The vibration frequency is the same throughout the test. None of these modalities gives any feedback when the object collides with an obstacle or with the wire.

B. *Hardware*

In the experiment, each participant had to wear a haptic device and a tracking device on his dominant hand.

The haptic device was built with a vibration micromotor attached to the thumb of each user with a Velcro strap (Fig. 6) An Arduino Nano board controls each vibration motor using PWM ports. Therefore, it is possible to control the vibration intensity of each micromotor separately. A host PC powers the Arduino Nano Board and handles the intensity of each micromotor via a USB connection.

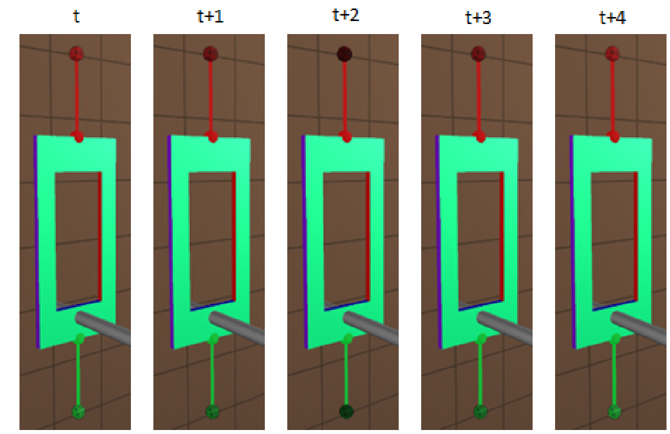

Fig. 5. Visual Feedback over the time t.

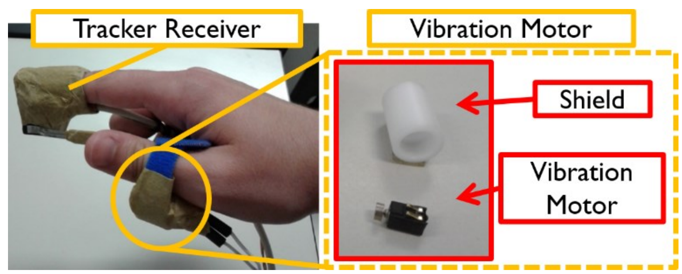

Fig. 6. Tactile device.

For tracking the user's movements, a Polhemus Fastrak© is used to track the index finger position of each user. Attached to each of these trackers there is a button used to select and hold the virtual object.

IV. EXPERIMENT PROTOCOL

The experiment was conducted in pairs. After signing a consent form, the participants were briefed about the equipment and the experimental task.

Each pair had to fill a questionnaire about their background, then perform the experiment and, finally, fill a post-test questionnaire about the experience they had. The experiment itself was divided in two phases.

In the first phase, the observer explained the idea of the SkeweR technique and how to interpret the feedback modalities. The observer also explained that the users should, during the interaction, try to keep the virtual pointer as near as possible to the original crushing points, and should avoid collisions between the object and the obstacles. After these instructions, the pairs had 5 minutes to train on how to collaboratively manipulate the virtual object using no feedback. For this training period and for the trials, they were advised to communicate with each other verbally, in order to better coordinate the cooperation.

In the second phase, the pairs were instructed to perform as many trials as possible during 15 minutes (this time was stipulated, after the pilot test, to avoid fatigue), by collaboratively moving the object from the beginning to the end of the course. The users had a break, in the middle of the experiment, of 1.5 minute.

All trials began with the object in the starting point and ended when the object reached the end of the wire. The modalities of interaction were alternated in each trial. The first modality was No Feedback , followed by only Visual Feedback and finally by the Tactile Feedback . The order of the first modality was changed along the pairs to reduce the learning effect.

A. Participants

The average age of the valid pairs (21 pairs) is 25.66 year-old ($\sigma^2 = 5.65$). Among these, 33 were males, 8 females and 1 skipped this question. 36 users were right-handed, 5 left-handed and 1 user declared himself as ambidextrous. In order to avoid the learning effect, 7 pairs ran the experiment starting with no feedback, 7 with visual and 7 with tactile feedback.

V. EXPERIMENT RESULTS AND DISCUSSION

Within the period of 15 minutes, each pair could perform an average of 22.57 (σ^2=6.52) trials, moving the object from the beginning to the end of the course.

A. Quantitative Results

In order to evaluate the performance of each feedback type, five metrics were used:

- time spent to finish each trial;
- number of times the hand position has been moved away from the crushing point;
- the amount of time that the hand position remained separated from the crushing point;
- the average distance between the crushing point and the hand position;
- the number of collisions between the manipulated object and the obstacles.

Fig. 7 shows the time spent to finish each trial (1st metric), based on the modality used. Considering each type of feedback, the average time to complete a trial was greater when using TF (21.12s and σ^2=7.41s) than with NF (18.73s and σ^2=7.25s) or VF (19.61 and σ^2=6.61). A one-way ANOVA, where $F_{2,471} = 3.690$, $p<.026$, shows that this differences between modalities are significant.

Comparing the modalities two by two, a t-test indicates that there is no significant difference between VF-NF nor TF-VF. However, the difference between TF-NF is statistically significant (p<.008) (Table I).

TABLE I.
P IN T-TEST BETWEEN GROUPS. IN TERMS OF AVERAGE TIME TO FINISH EACH TRIAL.

Groups	dof	t value	p<
VF-NF	314	1.093	.2751
TF-VF	314	1.612	.1079
TF-NF	314	2.656	.0083

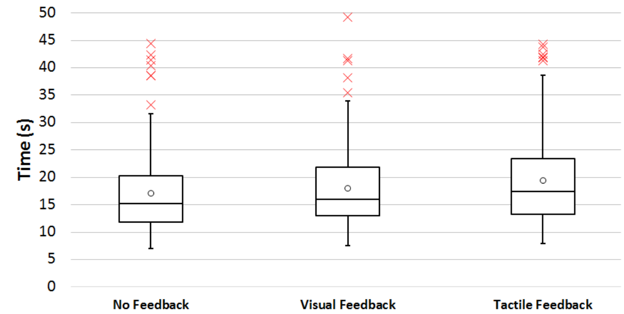

Fig. 7. Boxplot of completion time for each condition.

The 2nd metric computed the number of times the hand position has been moved away from the crushing point, during a trial. We call this the **Apart** event. This event is considered to happen whenever the distance between the hand and the crushing point is larger than a threshold. To register the end of the Apart event, the hand needs to move back to a distance smaller than the threshold. Table II shows the results for this metric. It is possible to see that trials with tactile feedback generate more Apart events. Fig. 8 shows the distribution of the amount of these events for each condition.

TABLE II
AVERAGE NUMBER OF *APART* EVENTS DURING EACH TRIAL

Feedback	Average	σ^2
None	20.00	8.06
Visual	21.24	7.95
Tactile	29.91	14.49

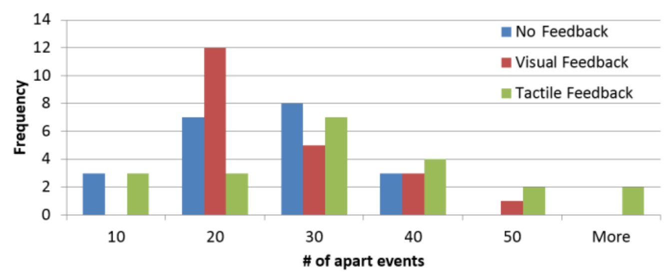

Fig. 8. Histogram of the number of Apart events by trial.

A one-way ANOVA, where $F_{2,60}$=7.59, p<.001, shows that the differences between modalities are significant. Comparing the modalities two by two, a t-test indicates that there is no significant difference between NF-VF, but the difference between TF-VF and TF-NF are statistically significant (Table III).

TABLE III.
P IN T-TEST BETWEEN GROUPS. IN TERMS OF *APART* EVENTS.

Groups	dof	t value	p<
VF-NF	40	0.489	.628
TF-VF	31	2. 346	.026
TF-NF	31	2. 671	.012

The third metric collected during the trials was the amount of time that the hand position remained apart from the original crushing point. In other words, this metric computes the duration of Apart events identified in the previous metric. Table IV shows the results of this metric for each condition. The TF was the one which took less time.

TABLE IV
DURATION OF *APART* EVENTS.

Feedback	Average (s)	σ^2(s)
None	2.041	3.417
Visual	2.107	3.417
Tactile	1.015	1.636

A one-way ANOVA with $F_{2,1491}$=25.942, p<.0001, shows that the differences between modalities are significant. Fig. 9 shows the distribution of these events for each condition. The graph shows that the Tactile Feedback has more shorter events than the other two conditions. Comparing the modalities two by two, a t-test indicates that there is no significant difference between VF-NF, however the difference between VF-TF and NF-TF is significant (Table V).

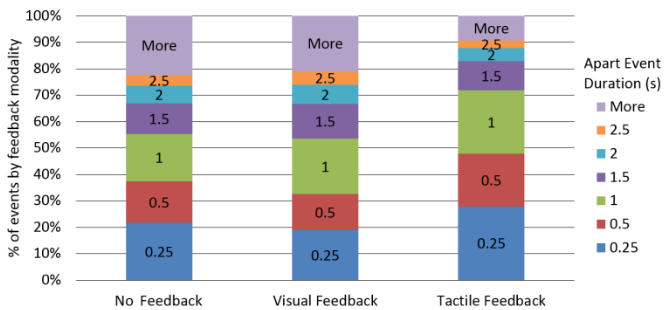

Fig. 9. Histogram of the duration of Apart events.

TABLE V
P IN T-TEST BETWEEN GROUPS. IN TERMS OF THE DURATION OF APART EVENTS.

Groups	dof	t value	p<
VF-NF	864	0.284	.777
VF-TF	591	6.255	.0001
NF-TF	549	5.727	.0001

The fourth metric represents the average distance between the crushing point and the hand position for each Apart event. Table VI shows the results of this metric. The one-way ANOVA test shows that the difference between the modalities is statistically significant, where $F_{2,1491}$=16.507, p<.0001. After the ANOVA, a t-test was performed to test if the difference between groups were significant. Table VII shows that there is no significant difference between Visual Feedback and Without Any Feedback, however, there is a significant difference between TF-NF and TF-VF.

TABLE VI
AVERAGE DISTANCE BETWEEN THE CRUSHING POINT AND THE HAND POSITION.

Feedback	Mean (cm)	σ^2 (cm)	Higher (cm)
None	2.859	2.015	18.835
Visual	2.825	1.938	19.177
Tactile	2.360	0.853	10.033

TABLE VII
P IN T-TEST BETWEEN GROUPS. IN TERMS OF ABSOLUTE DIFFERENCE.

Groups	dof	t value	p<
TF-NF	521	4.799	.001
TF-VF	568	4.756	.001
VF-NF	864	0.251	.802

Fig. 10 shows the distribution of these distances, classified by type of feedback. The graph shows that the Tactile Feedback has less events with mean distance higher than 3.25cm. For this condition, most of the mean distances are around 2.25 cm.

Fig. 10. Histogram of the absolute difference between crushing point and hand position.

The last metric analyzed the number of collisions with the obstacles (Obs) and the wire (Wire) of the scene. The percentage of collision with the obstacles or wire, during the task, was similar between the three types of feedback modalities (Table VIII). The one-way ANOVA test, where $F^{(Obs)}_{2,60}$ = 0.091, $p^{(Obs)}$ < .91 and $F^{(Wire)}_{2,60}$ = 0.199, $p^{(Wire)}$ <.82, indicates that the differences between modalities are not significant. A possible explanation for this result is the fact that the task did not generate any kind of penalty when the user collided with an obstacle or the wire, so the users did not care about this issue.

TABLE VIII
COMPARISON OF THE MEAN COLLISION BETWEEN THE FEEDBACK MODALITIES.

Feedback	$Collision^{(Obs)}$ (%)	$Collision^{(Wire)}$ (%)
Haptic	7.93	33.68
None	8.06	33.53
Visual	7.43	32.05

B. *Qualitative Results*

After the experiment, the users were asked to fill a questionnaire about it. The questions and answers are shown in Table IX, Table X, Table XI and Table XII.

TABLE IX
QUESTION 1 (%).

	Nothing	Some	A lot
How uncomfortable were you to wear the Velcro strap with the vibration micromotor?	47.5	47.6	4.8

TABLE X
QUESTION 2 (%).

	Very Short	Short	Ideal	Long
How do you feel about the experiment time?	0	4.8	40.5	52.4

TABLE XI
QUESTIONS 3 (%).

Question	TD	D	N	A	TA
(a) I thought the technique was easy to learn	0	11.9	4.8	42.9	40.5
(b) I could easily move the virtual object wherever I wanted;	0	16.7	26.2	40.5	11.9
(c) I could easily rotate the virtual object as I wanted;	4.8	14.3	23.8	42.9	14.3
(d) When I took away the CP from the initial CP, I could easily perceive it without any feedback;	7.1	38.1	14.3	26.2	14.3
(e) When I took away the CP from the initial CP, I could easily perceive it with visual feedback;	0	14.3	26.2	42.9	40.5
(f) When I took away the CP from the initial CP, I could easily perceive it with tactile feedback.	0	2.4	2.4	21.4	73.8

TD: Totally Disagree; D: Disagree; N: Neutral; A: Agree; Totally Agree.

TABLE XII
QUESTION 4 (%).

	NF	VF	TF	Not Answered
Which of the three types of feedback did you prefer?	0	9.5	88.1	2.4

On question 1 (Table IX), it was shown that more than 50% felt some sort of discomfort using the vibration micromotor. However, on questions 3 and 4 is possible to notice that most of them preferred to use the tactile feedback to correct the tracker position (Table XI (d, e, f) and Table XII). Also, when analyzing subjects' comments after the experiment, it is possible to notice that, frequently, the subjects (in VF and NF conditions) were not aware if the hand position was correct or not, or forgot to correct this. However, with the tactile feedback it became very easy to perceive that there was an issue that should be corrected.

These comments could explain why the number of Apart events (2nd metric) was higher with tactile feedback than the others, but the duration (3rd metric) and absolute distance (4th metrics) were lower than the other feedback modalities. As the tactile feedback is easily perceivable, even in an eyes-off interaction, as soon as the users notice the feedback, they try to correct their positions. While with no feedback or visual feedback, it could take a while for them to notice that they were not in the virtual object surface.

Also, when analyzing the comments from the questionnaire and the recorded communication during the task, it was possible to recognize that the users were confused when they had to return their hand position to the crushing point.

Concerning the overall experience, most users had no problems to use the technique during the experiment (Table XI, questions a, b and c). However, most of them felt that the experiment time was too long (Table X, question 2).

VI. FINAL REMARKS

This work presented the evaluation of three different types of feedback applied to a collaborative manipulation technique. We ran a set of trials that showed that the use of visual or tactile feedback makes no significant difference on task completion time.

However, once the Apart event happens, the tactile feedback showed itself as the most effective way to keep the distance small, and to reduce the time of this event.

As future work, we suggest to add a penalty for the users when they collide the shared object against an obstacle or the wire. In this case, the shared object would return to a previous position, and would be disconnected from the users' hand.

ACKNOWLEDGMENTS

Our research is partially funded by (a) the National Institute of Science and Technology in Medicine Assisted by Scientific Computing (Grant CNPq 181813/2010-6) and (b) CAPES/PROSUP – Program for Supporting Gratuate Program in Private Higher Education Institutions (Grant CAPES 181/2012).

REFERENCES

[1] C. Fleury, T. Duval, V. Gouranton and A. Steed, "Evaluation of remote collaborative manipulation for scientific data analysis," *VRST'12,* pp. 129-136, 2012.

[2] M. S. Pinho, D. A. Bowman and C. M. D. S. Freitas, "Cooperative object manipulation in immersive virtual environments: framework and techniques," *VRST'02,* pp. 171-178, November 2002.

[3] S. Otmane, N. Ouramdame-Djerah and M. Mallem, "Towards a Collaborative 3D Interaction Model for Cooperative Design in Virtual Environments," *CSCWD'07,* pp. 198-203, 2007.

[4] M. Cabral, G. Roque, M. Nagamura, A. Montes, E. Z. Borba, C. Kurashima and M. Zuffo, "Batmen – Hybrid Collaborative Object Manipulation Using Mobile Devices," *3DUI'16,* p. 2, 19-20 March 2016.

[5] L. Pavanatto Soares, T. Volpato de Oliveira, V. Abichequer Sangalli, M. Sarroglia Pinho and R. Kopper, "Collaborative hybrid virtual environment," *3DUI'16,* pp. 283-284, March 2016.

[6] N. Baron, "CollaborativeConstraint: UI for Collaborative 3D Manipulation Operations," *3DUI'16,* pp. 273-274, 19-20 March 2016.

[7] T. Duval, A. Lécuyer and S. Thomas, "SkeweR: a 3D Interaction Technique for 2-User Collaborative Manipulation of Objects in Virtual Environments," *3DUI'06,* pp. 69-72, August 2006.

[8] A. Bloomfield and N. I. Badler, "Collision Awareness Using Vibrotactile Arrays," *VR'07,* pp. 163-170, 14-17 March 2007.

[9] Q. An, Y. Matsuoka and C. E. Stepp, "Multi-day Training with Vibrotactile Feedback for Virtual Object Manipulation," *ICORR'11,* pp. 1-5, 29-1 June-July 2011.

[10] J. M. Walker, A. A. Blank, P. A. Shewokis and M. K. O'Malley, "Tactile Feedback of Object Slip Improves Performance in a Grasp and Hold Task," *HAPTICS'14,* pp. 461-466, 2014.

[11] H. Salzmann, J. Jacobs and B. Froehlich, "Collaborative interaction in co-located two-user scenarios," *EuroVR'09,* pp. 85-92, 7-9 December 2009.

[12] L. Aguerreche, T. Duval and A. Lécuyer, "Reconfigurable tangible devices for 3D virtual object manipulation by single or multiple users," *VRST'10,* pp. 227-230, 5 December 2010.

[13] R. A. Ruddle, J. C. Savage and D. M. Jones, "Symmetric and asymmetric action integration during cooperative object manipulation in virtual environments," *TOCHI'02,* pp. 285-308, 2002.