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USAGE OF TACTILE FEEDBACK TO AID COOPERATIVE OBJECT MANIPULATION IN VIRTUAL ENVIRONMENTS

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USAGE OF TACTILE FEEDBACK TO AID COOPERATIVE OBJECT MANIPULATION IN VIRTUAL ENVIRONMENTS

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Thesis submitted to the Pontifical Catholic University of Rio Grande do Sul in partial fulfillment of the requirements for the degree of Master in Computer Science.

Advisor: Prof. Dr. Márcio Sarroglia Pinho

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Dedicatória

Gostaria de agradecer primeiramente à toda minha família, que me deu suporte em diversos momentos da minha vida. Em especial à minha mãe, que sempre me ajudou e me apoiou.

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USO DE RETORNO VIBROTATIL PARA A AUXILIAR NA MANIPULAÇÃO COOPERATIVA DE OBJETOS EM AMBIENTES VIRTUAIS.

Resumo

Realidade virtual é uma tecnologia que permite aos seus usuários visualizar e interagir com ambientes virtuais (AV) 3D em tempo real. Um ambiente virtual colaborativo (AVC) é um tipo de AV que permite que dois ou mais usuários estejam juntos no mesmo ambiente virtual. Ambientes virtuais colaborativos têm algumas dificuldades que AV comuns não têm. Por exemplo, diferentes técnicas são necessárias a fim de permitir a dois usuários a manipulação (mover ou girar) conjunta de um objeto virtual. Algumas dessas técnicas podem levar os usuários a realizarem movimentos não naturais.

Este trabalho avalia o retorno háptico para deixar os usuários cientes de movimentos errados durante a manipulação colaborativa de objetos. A técnica SkeweR foi utilizada como teste. Esta técnica é baseada em *crushing points*, onde os usuários pegam o objeto pela primeira vez para simultaneamente mover e girar o objeto. Uma vez que os usuários mantêm a posição da mão sobre o *crushing point* durante a manipulação do objeto, a interação se torna mais natural, no sentido de que se torna mais similar ao processo real de segurar um objeto. Entretanto, devido à falta de restrições físicas de movimento, frequentemente, durante a interação, a mão do usuário se move para fora do *crushing point*.

Para solucionar este problema, este trabalho propõe o uso de retorno tátil para informar os usuários sobre a distância entre a posição da mão e o *crushing point*. O retorno tátil é fornecido por um minimotor de vibração preso no polegar do usuário. Para validar o método, fez-se um estudo com usuários em que estes deveriam realizar a manipulação 3D de um objeto virtual. Este objeto precisava ser transladado e girado através de um caminho virtual ao longo de um fio virtual, do início deste até o fim.

Durante a interação, os usuários manipularam um rastreador de posição com três graus de liberdade (3DOF) e deveriam manter a posição do rastreador na mesma posição do *crushing point*. Durante as rodadas do experimento, os participantes testaram três modalidades de interação: sem nenhum retorno, com retorno visual e com retorno tátil. O resultado dos testes mostrou que usuários realizaram manipulações mais naturais quando estavam usando o retorno tátil.

Palavras-Chave: Awareness Feedback, Retorno Háptico, Manipulação 3D, Realidade Virtual

USAGE OF TACTILE FEEDBACK TO AID COOPERATIVE OBJECT MANIPULATION IN VIRTUAL ENVIRONMENTS

Abstract

Virtual reality is a technology that allows users to view and interact with a 3D virtual environment (VE) in real time. A collaborative virtual environment (CVE) is a type of VE that allows two or more users to be in the same virtual environment together. Collaborative virtual environments have some issues that simple VEs do not have. For example, different techniques are required in order to allow two users to manipulate (move or rotate) a virtual object together. Some of these techniques can lead users to do unnatural movements.

This study evaluates haptic feedback to let users aware of wrong movements during a cooperative object manipulation. The SkeweR technique was used as a testbed. 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 users have their hands 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 users' hands move away 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 between his hand and the crushing point. The tactile feedback is provided by a vibration micromotor attached to the user's thumb. To validate the method, a user study based on the 3D manipulation of a virtual object was performed. The virtual object had 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 manipulated a three degrees of freedom (3DOF) position tracker and were requested to keep this tracker in 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 do more natural manipulations when using tactile feedback.

Keywords: Awareness Feedback, Haptic Feedback, 3D Manipulations, Virtual Reality

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List of Abbreviations

ANOVA – Analysis of Variance
CP – Crushing Point
DOF – Degrees of Freedom
ERM – Eccentric Rotation Mass
HP – Hand Position
NF – None Feedback
PWM – Pulse-Width Modulator
TF – Tactile Feedback
VF – Visual Feedback

Summary

1 Introduction

Virtual Reality is a technology that allows users to view and interact in real time with three dimensional virtual environments. In these environments, the sense of sight is the most used for the interaction; however, other senses such as touch, smell and hearing can also be used.

There are several areas of application for virtual reality, such as training, simulation, entertainment, and visualization, where it is interesting, sometimes, that more than one user can simultaneously interact and manipulate the data collaboratively, thus increasing the involvement of these users and their understanding of the data analysis [1]. Additionally, the multi-user approach can be helpful in tasks that are difficult to perform alone, such as moving a virtual object through a door, given that a single user cannot have an overview of the complete environment [2].

In the context of virtual environments, collaborative manipulation refers to the simultaneous manipulation of virtual objects by multiple users [2] [3]. The use of collaborative manipulation can be helpful in situations in which a single user can have trouble performing a task, such as when there is an obstacle preventing the correct manipulation of the object, thus being necessary that the user move the object to another location in order to complete the task. In this situation, a second user, positioned in a different location, can help the first user manipulate the object [2].

There are many approaches to collaborative manipulation, but all of them need to solve two basic problems: how to generate the shared object movement composing interactions from the manipulations performed by each user and how to provide the proper **awareness feedback** about the partner’s actions.

For the first issue, most works separate the degrees of freedom (translation, rotation) among the users [2] [4] [5] [6], separate the degrees of freedom and define some motion restriction point [7], or use only the translation of two users to compose the virtual object position and orientation, such as the SkeweR technique [8].

In addition to composing the users’ actions to apply the proper transformations over the shared object, **awareness feedback** is also a very important issue in collaborative manipulation because it can help users on manipulations [2] by making them aware of manipulation events, such as selection of an object by their partners or collisions of the shared object. Visual feedback is the most used medium to generate awareness, as it requires no additional hardware [9]. However, this medium is not always the best option to convey information, given that, in the real world, the forces transmitted from one user to another, through the shared object, are fundamental to human interactions. Therefore, the addition of haptic feedback can improve human interactions in virtual environments based only on sight.

Based on that, the present work proposes to evaluate how the use of haptic feedback can help users perform a collaborative task in virtual environments.

The SkeweR interaction technique was chosen as this work's test bed [8]. When using this technique, to start the collaborative interaction, each user grabs the object by one **crushing point**, similar to when handling the extremity of a skewer. During this interaction, while each user is moving his hand, new positions and orientations are computed for the shared object, based on the positions of both users' hands.

Since there is no device that prevents the users from moving their hands off the crushing points, the greater the distance between the crushing points and the users' hands grows, the more unnatural the interaction becomes. Figure 1 **Erro! Fonte de referência não encontrada.** (t=0) shows the moment when the users grab the object; at this time, their hand positions and crushing points are the same. After grabbing the object, if the users move their hands away from the crushing point, they will not be holding the object anymore (**Erro! Fonte de referência não encontrada.** Figure 1 t=1 and t=2).

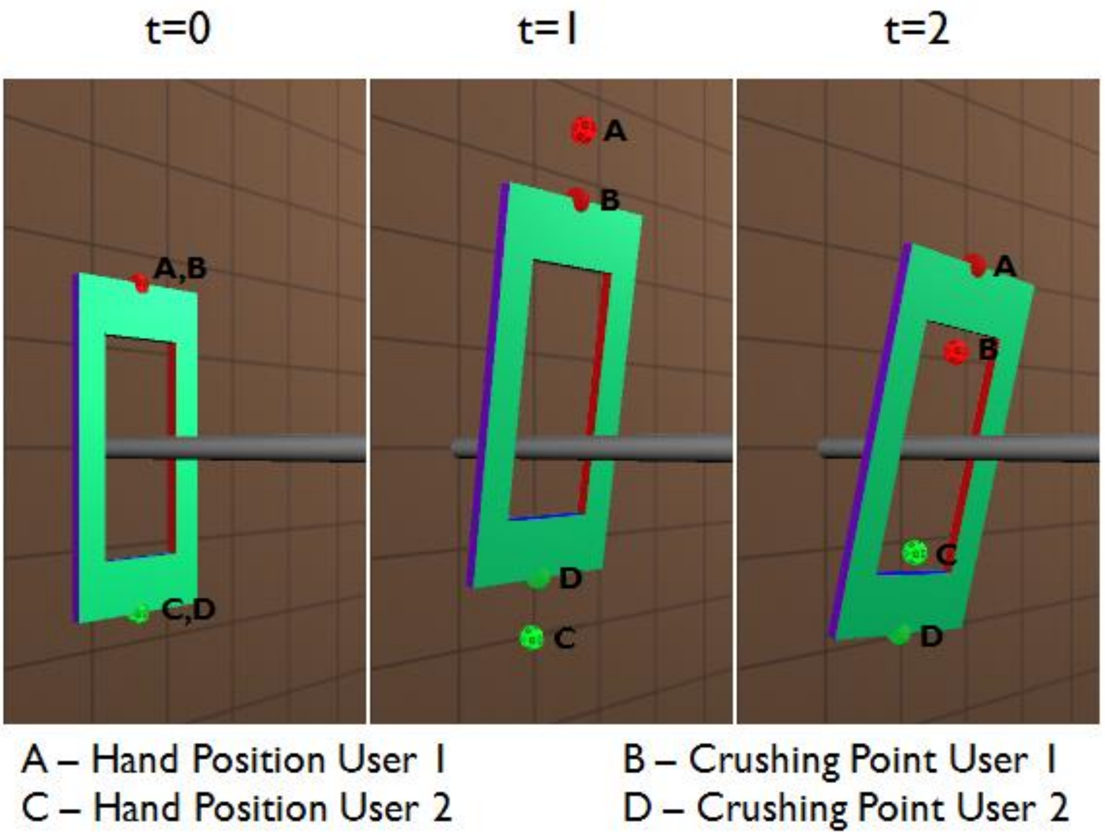


Figure 1 – Crushing point and real hand position over time.
Source: Author (2017).

In this context, the main objective of this work is to **evaluate how the use of a haptic feedback can help users perform a more natural and precise collaboration.**

In order to do so, the study strives to answer the following research questions:

1. Do users execute faster and more coordinated manipulations using haptic feedback (in comparison to when performing without it)?
2. Does the usage of haptic feedback on collaborative manipulation of virtual objects help users be aware of wrong movements executed during the collaboration?

Mapping these questions to the test bed technique, two hypothesis are formulated:

H1: When users use haptic feedback, they perform more coordinated manipulations, and, as a consequence, the number of collisions between the object and the scenario decreases.

H2: When users use haptic feedback, it is easier for them to be aware of unnatural hand positions.

This work is organized as follows: the next chapter presents a few basic concepts used in virtual reality as well as different collaborative manipulation techniques. After that the usage of haptic feedback during interaction to improve the user experience.

Chapter 3 describes the concepts used in the proposed technique and how that technique is developed in this work.

Chapter 4 describes the experiment design, which shows how the technique was implemented, the virtual environment used in the test, the real setup and the hardware used in this experiment.

Chapter 5 specifies the procedure protocol used to perform the test and the demographic statistics of the users.

Chapter 6 presents the quantitative and qualitative metrics used to analyze the effectiveness of the technique. After that, the results are presented and discussed. Finally, Chapter 7 offers a few final remarks and suggestions on how to improve the developed technique.

In the end, chapter 8 presents the bibliography which were used in this work.

2 Related Work

This chapter in divided in two sections. The first one presents an overview of previous works on collaborative manipulation techniques, dedicating special attention to the SkeweR technique, which is used in this work. The second part presents ideas on how a collaborative technique can provide feedback to collaborating users in order to facilitate the understanding of their partner's actions. In the section, special attention is devoted to haptic feedback and how previous works have applied haptic feedback to interactions with virtual objects.

2.1 Collaborative Manipulation

Collaborative manipulation refers to the simultaneous manipulation of virtual objects by multiples users [10] [3]. In collaborative environments, it is important that all users are aware of their partners' actions [2]. For example, when a user selects an object that is already being used by another user, both users need to understand this action [10].

Among the existing approaches to collaborative manipulation, the most common way to combine users' movements is to decompose the movement of each user in its degrees of freedom (DOF) and then combine the DOFs in some specific way.

In the context of virtual reality, the degrees of freedom are the number of independent dimensions of a body's motion [9]. They can be used to describe object movements (translation or rotation) along the coordinated axis (X, Y, or Z).

In the average technique presented by Ruddle et al. [11], two users can manipulate the same DOF. Based on the translations and rotations applied by the users, the technique computes the object's movements by performing an average of the translations and rotations carried by each of them. The principle of this technique is shown in Figure 2.

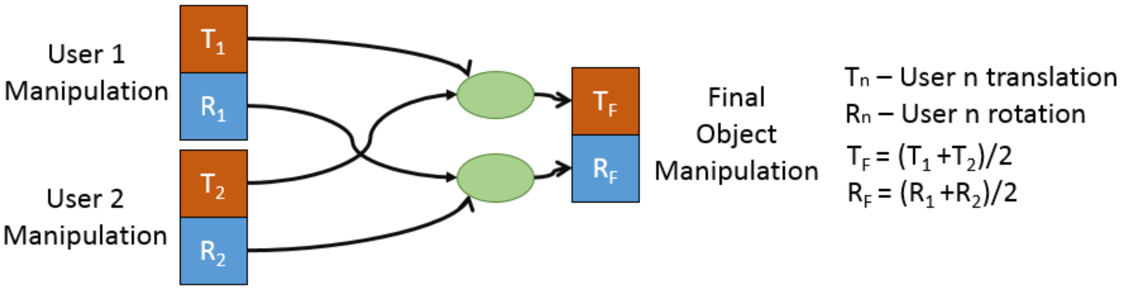


Figure 2 – Arquitecture of the Ruddle et al. technique [11].
Source: Adapted from Duval et al. [8] (2006).

Using the same idea, Riege et al. [12] merge multiple inputs by interpolating the rotations and translations. The rotations are obtained through the Slerp algorithm [13], and the translations are calculated using the average of all input translations. Each input translation has a different weight based on how much the users are translating the objects.

Instead of computing the final movement of the object by mixing translation and rotation operations, Pinho et al. [10] split the degrees of freedom among the users. The principle of this technique is presented in Figure 3.

Soares et al. [5] control the collaborative manipulation in the same way. However, the translations and rotations are performed using different view points – exocentric view and egocentric view, respectively. With the exocentric view, the user is far from the object and has a broad view of the scene, an ideal solution for high amplitude translations. With the egocentric view, the user is near the object and can perform more precise rotations, it automatically controls the positions of the users while interacting.

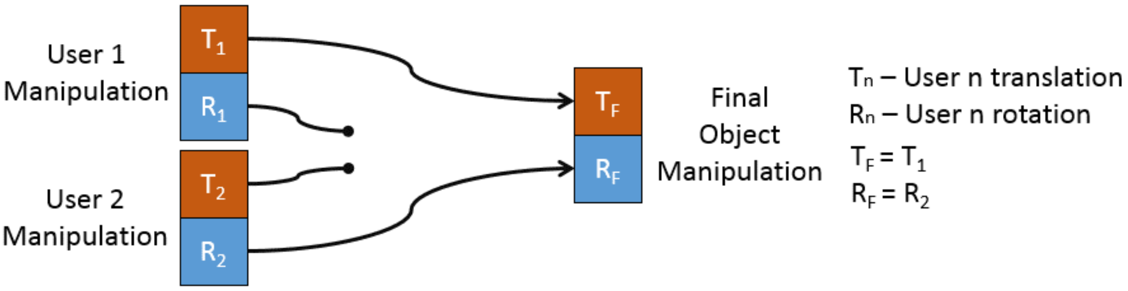


Figure 3 – Architecture of a technique that splits the DOFs (only translation and rotation operations are shown).
Source: Adapted from Duval et al. [8] (2006).

In the technique proposed by Baron [7], on the other hand, every user in the environment can perform any manipulation. However, to apply the manipulation, all users must accept it. When using this technique, users have to define some constraints to manipulate the virtual object, using operations of translation, rotation and scaling. The architecture of this technique is shown in Figure 4.

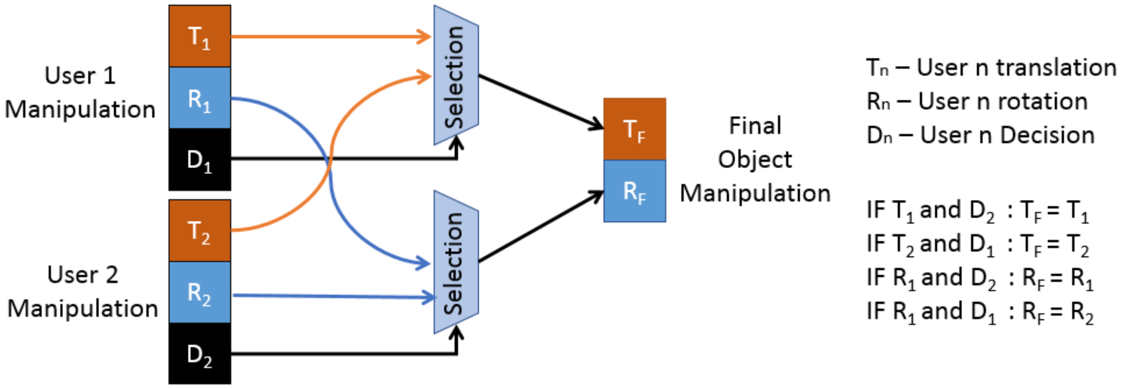


Figure 4 – Arquitecture of the Baron technique [7].
Source: Author (2017).

Another possibility is explored in the work of Cabral et al. [4], who uses 9 DOFs for the manipulation of the object. The manipulations are performed with a cell phone, and the technique allows different users to simultaneously perform all the operations at the same time. The result of the object manipulation is the sum of all individual manipulations of the object, as shown in Figure 5. Identically, Grandi et al. [6] perform the sum of all individual manipulations to generate the final manipulation. However, only one degree of freedom is used to perform the scale operation, making it a uniform scale along all axes.

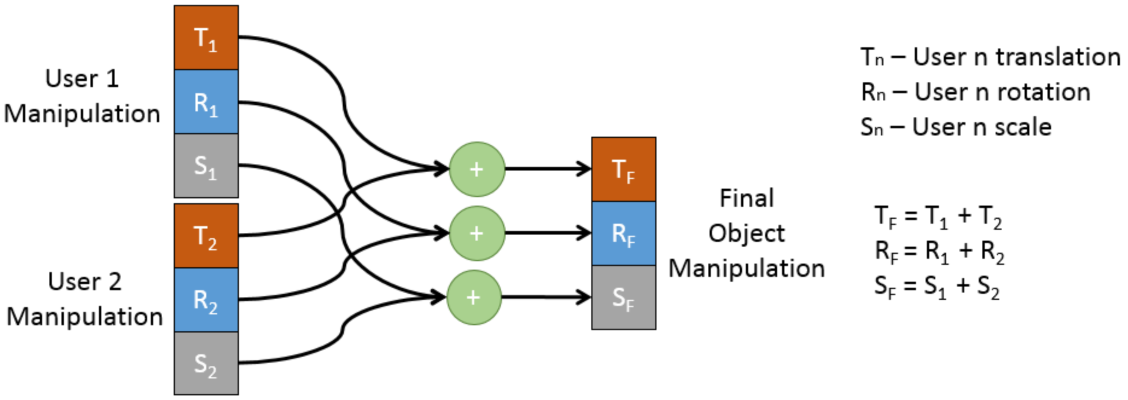


Figure 5 - Arquitecture of the Cabral el at. [4] and Grandi et al. [6] techniques.
Source: Author (2017).

Differently from the previous techniques, Duval et al. [8] designed a technique called *SkeweR*. This technique uses the users' hand position (HP) to translate and rotate a virtual object. It is based on crushing points (CP), defined on the object’s surface by the point where the user grabs the object. This technique was designed to be performed with two users in a collaborative manipulation. However, it also allows the use of only one CP, a single user.

This technique gives the users the impression that they are pulling the object with a virtual cord; for example, if the users move their hands in opposite directions, the combined movement will rotate the object, as can be seen in Figure 6 (e). Equations 1, 2, 3 and 4 show how the position and rotation of the manipulated object are calculated.

In Equation 1, Pc1 is the position where user 1 is grabbing the virtual object, Pc2 is the position where user 2 is grabbing the virtual object, Po is the position of the virtual object and R is the orientation of the virtual object in quaternion notation.

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

In Equation 2, V is the vector formed by the position Pc1 to Pc2, which is used in Equations 3 and 4 to find the rotation (Equation 3) and axis of rotation (Equation 4). The notations t and t+1 indicate the vector in the time t and the time plus one frame, respectively.

$$\vec{v} = \overrightarrow{Pc_1 Pc_2} \tag{2}$$

$$\theta = \tanh^{-1}(\frac{\overrightarrow{v_t} \cdot \overrightarrow{v_{t+1}}}{\|\overrightarrow{v_t}\| \times \|\overrightarrow{v_{t+1}}\|}) \tag{3}$$

$$\vec{\omega} = \overrightarrow{v_t} \wedge \overrightarrow{v_{t+1}} \tag{4}$$

Figure 6 represents the application of the SkeweR technique as well as the formulas listed above. In Figure 6 (a), two users are moving their hands with the same velocity vector from time t=0 to t=1. Thus, the virtual object moves with the same velocity vector, and the crushing points and hand positions are the same during the interaction. Additionally, in Figure 6 (b), when only one user moves his hand, the final position of the virtual object is the arithmetic mean of the two hand positions, and it is possible to notice that the hand position is not anymore on the virtual object surface, as shown in Figure 6 (a). The same effect occurs in Figure 6 (c), in which the two users move their hands with a velocity vector of opposite directions; as a result, the object does not move. The first term of the Equation 1 explains why the object is always in the middle point of the line between the two hand positions. Figure 6 (d) exemplifies a situation in which one user does not move his hand while the other one makes circular movements around the first user's hand position, maintaining the same radius established when they first grabbed the virtual object. Figure 6 (e, t=0) shows two users moving their hands in opposite directions with different velocities, and Figure 6 (e, t=1) shows that the distance between any hand position and the object is the same, no matter the velocity.

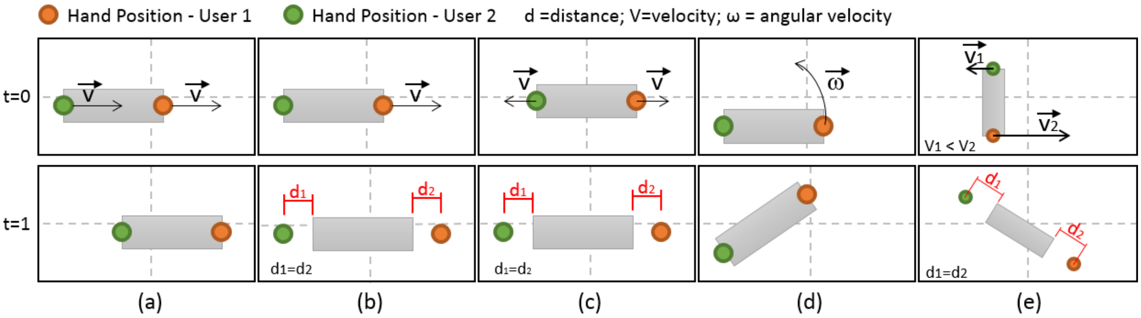


Figure 6 – Examples of use of the SkeweR technique.

Source: Author (2017).

The principle of the SkeweR technique is presented in Figure 7. It is considered a hybrid of the Ruddle et al. [11] and Pinho et al. [10] techniques.

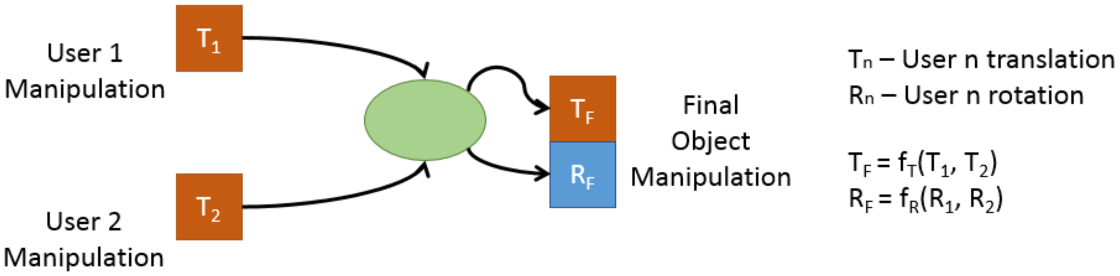


Figure 7 – Architecture of the SkeweR technique [8].
Source: Adapted from Duval et al. [8] (2006).

2.2 Feedback for collaboration awareness

As mentioned in the previous section, when more than one person is involved in the interaction, all users should be aware of the other users' actions, since it is extremely difficult to perform a collaborative interaction in situations in which no awareness feedback is provided [14]. The most common approach to transmit information about the other users is visual feedback, given that it requires no special device [9].

Pinho et al. [2] divided the awareness in three categories: user information, interaction information, and object state information. To provide user information, the technique uses a 3D avatar that represents the user's hand and body, letting the partner aware of his position and where he is looking at (Figure 8). The information about the interaction is used to allow the partner to understand which interaction technique the user is using and which degrees of freedom each user can control. Figure 9 shows a ray of the ray-casting technique and 3D icons that convey information about which translation/rotation the users can control. The information about the state of the object is useful to understand if the object is being manipulated and by which user.

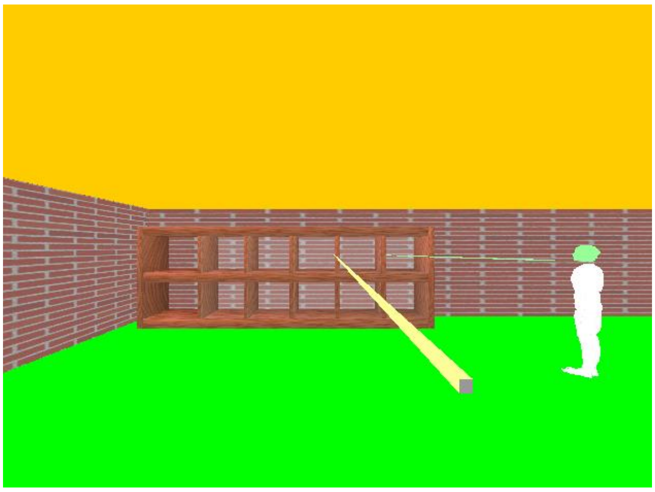


Figure 8 – Representation of partner's avatar.

Source: Pinho et al. [9] (2008).

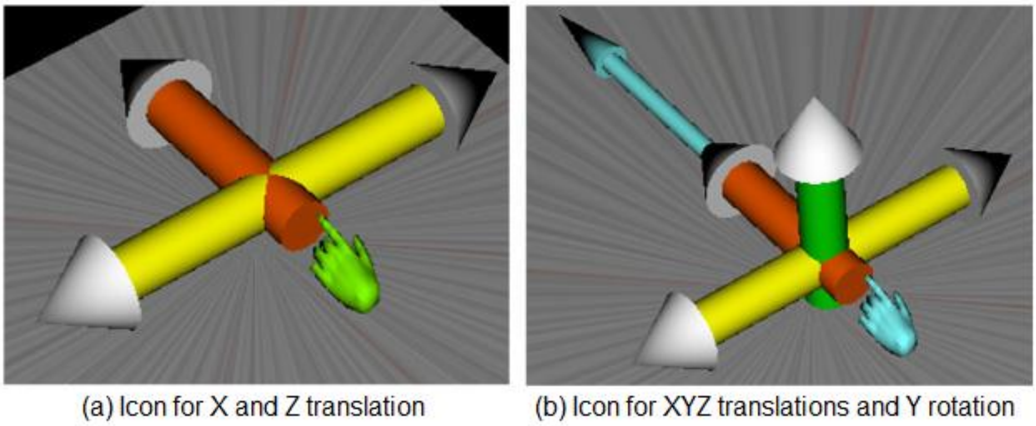


Figure 9 – Example of 3D icons for interaction information awareness.

Source: Pinho et al. [9] (2008).

Another possibility is presented by the work of Riege et al. [12], who tested a curved ray as a visual feedback. In this technique, two users apply a ray-casting technique to manipulate the same virtual object. However, the ray orientation and position may drift from the original tracker orientation and position over time. To circumvent this problem, a bent ray is used to convey the information that two or more users are manipulating the same virtual object. With this technique, the ray starts on the same orientation/position of the tracker and, when the ray position/orientation differs from the position/orientation of the tracker, it makes a curve to hit the virtual object in the same place it was hit the first time (Figure 10), to show that the two users are manipulating the same virtual object.

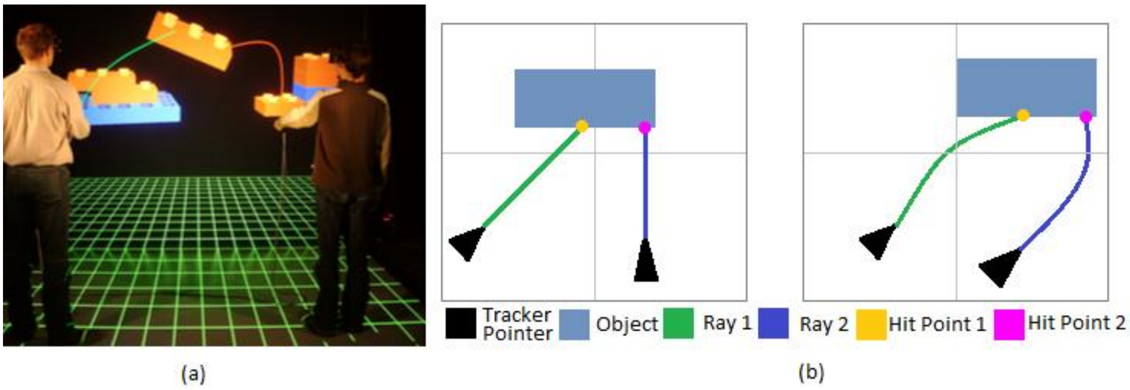


Figure 10 – Two users collaboratively dragging an object using the Bent Pick Ray Technique.

Source: (a) Riege et al. [12] (2006) and (b) Author (2017).

2.3 Vibratory feedback for supporting interaction awareness

Approaches based solely on images, although common, can lead to an overload of the visual channel. Therefore, the usage of haptic devices can be an alternative to convey different information.

Due to its low price and simple interface, the most popular device currently used for providing tactile feedback is the vibration motor. This device, although simple, can transmit different feedbacks by varying the vibration frequency, amplitude, and the position it assumes on the body. For example, some videogame controllers have vibration motors to inform the user that something just happened, such as a collision [9]. Vibratory feedback is also used in cell phones to notify something relevant to the user.

This subsection reports some uses of vibratory feedback to aid users' interaction and perception of the environment.

Bloomfield et al. [15], for example, use different intensity levels of vibration to inform how much a virtual object is inside another virtual object during a collision. Also, shallow collisions do not give any feedback, because the technique assumes the possibility that the user's skin might be deformed due to contact with other surfaces (Figure 11 (c)); medium depth collisions are informed with a continuous vibration (Figure 11 (d)); and deep collisions are informed with a 200ms pulse period, to alert the user to the situation's "urgency" (Figure 11 (e)).

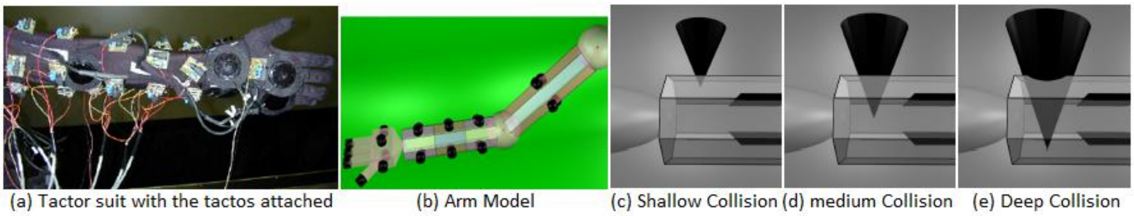
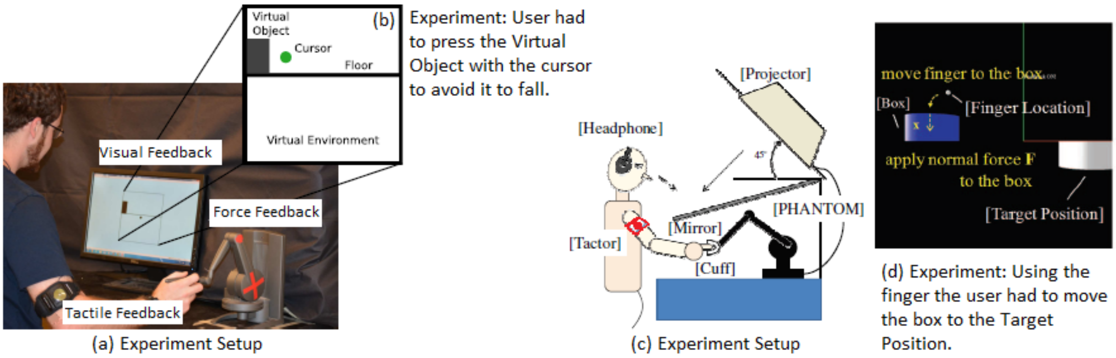

(a) Tactor suit with the tactos attached (b) Arm Model (c) Shallow Collision (d) medium Collision (e) Deep Collision

Figure 11 – Bloomfield et al. work [15].
Source: Adapted from [15] (2007).

Other studies use a simplified collision feedback in order to guide the user while interacting with an object. In the work of An et al. [16], for instance, a vibration motor is placed on the user's arm to inform him when it is necessary to apply more force on a virtual object to move it, or less force to prevent it from breaking (Figure 12 (c) and (d)). The amount of force applied over an object is informed based on the linear variation of the motor's vibration. Similarly, Walker et al. [17] use the same device to inform the user when it is necessary to apply more force on an object to prevent it from falling. In this case, the device is attached to each user’s dominant arm (Figure 12 (a) and (b)). The intensity of the vibration is linearly proportional to the falling acceleration of the object.



Experiment: User had to press the Virtual Object with the cursor to avoid it to fall.

(a) Experiment Setup

(c) Experiment Setup

(d) Experiment: Using the finger the user had to move the box to the Target Position.

Figure 12 – Setup and virtual experiment of Walker et al. [17] (a) and (b) and of An et al. [16] (c) and (d).
Source: Adapted from [16] (2011) and [17] (2014).

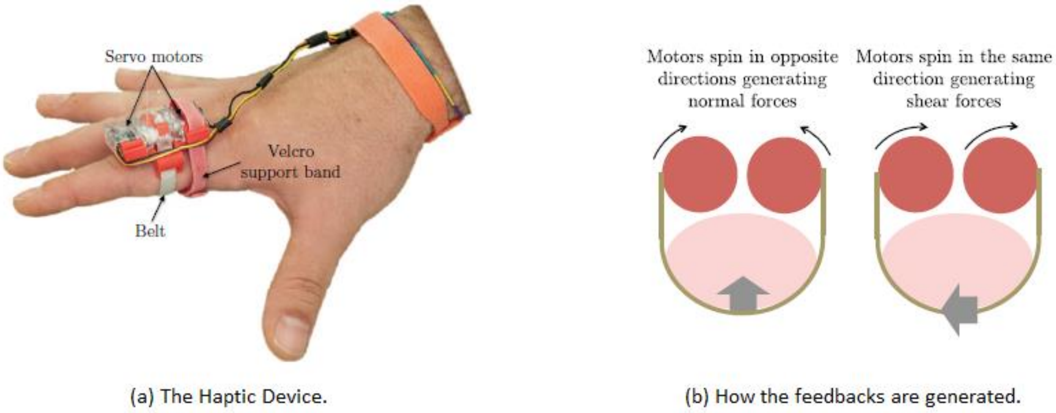
Gartia et al. [18] also investigate the use of a haptic device to prevent the fall of the object being manipulated. The authors analyze multimodal feedback in a technique that simulates a rubber band connecting the users’ hands to the virtual object. If the users’ hands move in opposite directions, the rubber band breaks and the object falls. To inform that an object is close to falling, this technique adopts visual, sound and vibrotactile feedback. In the last one, the vibration is proportional to how close the object is to falling. A test with 4 types of feedback showed that any type of feedback is better than no feedback. Also, the tactile feedback produced the best results among the tested types of feedback, given that vibratory feedback does not overlaps the visual channel.

In order to guide the user specifically on the grabbing phase of the interaction process, Niinimake et al. [19] compare the use of haptic (Figure 13 (a)) and audio feedbacks to inform the user if an object can be moved to another place. The haptic feedback is provided by a glove equipped with a vibration motor in its palm. In the same line, Moehring et al. [20] investigate the effectiveness of different modalities of feedback to grasp virtual objects. As a reference interaction, they use a Flystick [20], an input device commonly used in industrial applications. Two types of haptic feedback are used in this approach: pressure or vibration, located on the user’s fingertip (Figure 13 (b) and (c)). The time taken to complete the task was measured, and the results show that there is no significant difference, in the act of grasping, between the two types of haptic feedback tested. This result is due to the fact that the researchers implemented grabbing feedback instead of collision feedback.

(a) Location of the motor (b) Device with Pressure Feedback (c) Device with Vibration Feedback

Figure 13 – Reception points for haptic feedback in (a) Niinimake et al. [19] and (b) (c) Moehring et al. [20].
Source: (a) adapted from [19], (b) and (c) adapted from [20].

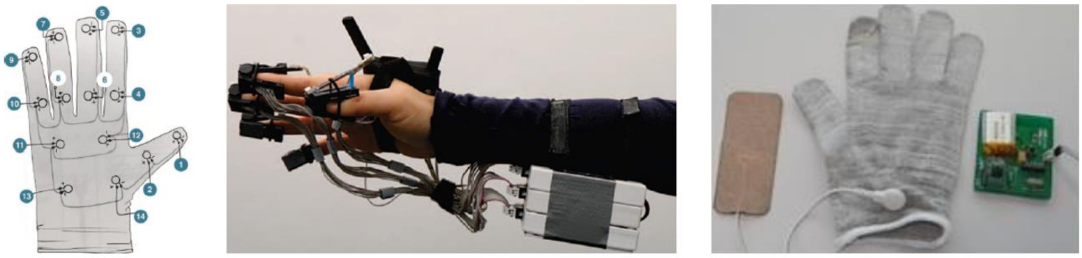
In a more complex setup, Pacchierotti, et al. [21] present a haptic device that generates normal and shear forces (Figure 14 (a)). The device, called hRing, is worn on the user’s index finger proximal phalanx and has a fabric belt attached to two motors. If the two motors rotate in the same direction, the device generates shear forces, if the motors rotate in opposite directions, it generates normal forces Figure 14 (b)). A test in which the users grab virtual objects indicated that users who used the device applied less force on the virtual objects than the users who did not.



(a) The Haptic Device. (b) How the feedbacks are generated.

Figure 14 – hRing, the haptic device developed by Pacchierotti et al. [21].
Source: Pacchierotti et al. [21].

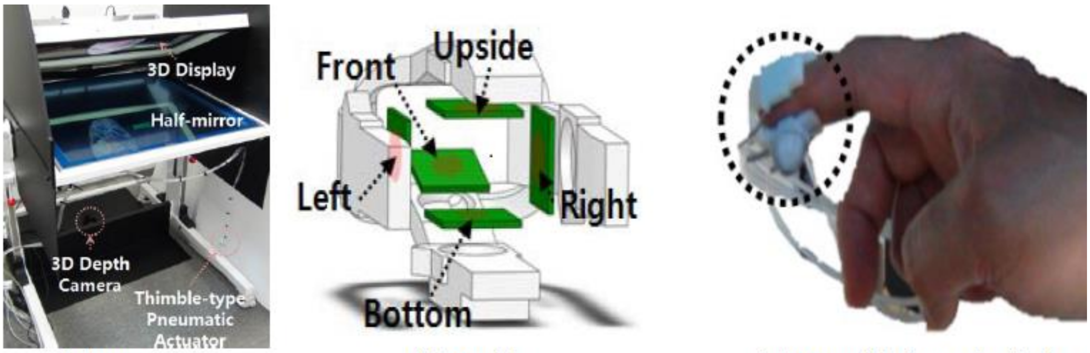
Other authors also developed devices to convey the feeling of touch, such as Giannopoulos et al. [22], Hummel et al. [23] and Pamungkas et al. [24] Giannopoulos et al. [22] use a vibration motor on the user’s palm to provide the sensation of touch (Figure 15 (a)). The intensity of the vibration is based on the number of virtual collisions around the vibration motor. Hummel et al. [23] use an electrotactile feedback device on each finger to represent the felling of pressure when a virtual object is touched (Figure 15 (b)). The developed device can distinguish depths between 0 and 25mm. Depth is represented using electric patterns that are divided in 5 linear scales. Pamungkas et al. [24] also work with electrotactile feedback. The authors developed a device that conveys different sensations on the user's hand (Figure 15 (c)). In their work, a combination of different frequencies and intensities is used to represent three different sets of information: touch, impact and warm-hot-burn sensations.



(a) Location of motors. (b) Location of electrotactiles devices. (c) Glove and the electrotactile device.

Figure 15 – Haptic devices developed by (a) Giannopoulos et al. [22], (b) Hummel et al. [23] and (c) S. Pamungkas et al. [24].
Source: (a) Giannopoulos et al. [22] (2012), (b) Hummel et al. [23] (2016), (c) S. Pamungkas et al. [24] (2016).

The work of Han et al. [25] investigates the usage of a haptic device, placed on the user's index finger, that gives the feeling of contact, direction and movement (Figure 16). These sensations can be informed by producing patterns, using balloons that can be inflated and generate the sense of spinning, bouncing, and pressure. Results show that users have better control of interactions with 3D virtual objects when they are provided with haptic feedback – in opposition to performing without this type of feedback.



(a) Setup (b) Model (c) Wearable fingertip display

Figure 16 – Device developed by Han et al. [25]
Source: Han et al. [25].

2.4 Passive Haptic Feedback

Besides active tactile feedback, another common approach for supporting the awareness of a partner in a collaborative virtual environment (CVE) is the use of passive feedback. The idea behind this approach is to give a physical link between the two users [26], this way, the users understand the dimension of the virtual object.

Salzmann et al. [26], for example, evaluate the use of a passive haptic device in an assembly task in which two users have to move an object in a virtual environment. Once both users have caught the virtual object, its position and orientation is calculated by the average of the users' hand position and orientation. During the evaluation, the first test is solely based on visual feedback. The second applies a passive haptic feedback to limit the users' movements, making them hold a real-world handle that mimics the position where the users had to catch the virtual object in the virtual environment (Figure 17). When using this handle, if a user moves his arm, the action is easily perceived by his partner. The study indicates that tests realized with passive haptic feedback are more efficient when it comes to both the task completion time and precision.


(a) passive haptic device (b)Virtual Environment (c) without passive haptic device

Figure 17 – Comparison of prop-based and virtually manipulated techniques

Source: Salzmann et al. [26] (2009).

Aguerreche et al. [27] also use a passive haptic feedback technique to improve virtual object manipulation. However, they use a reconfigurable tangible device (RTD) that can be adapted to roughly match the shape of a virtual object (Figure 18 (a)). This device has handles that can be compressed or stretched to form a representation of a virtual object. This technique was tested with a device using 3 connection points (Figure 18 (a)), and 4 connection points (Figure 18 (b)). If compared with two other techniques (Ruddle’s Mean Technique [11] and Separation of Degrees of Freedom technique [11] [2]), Aguerreche et al.’s work shows that RTD has a significant effect on the realism, training, and presence. However, there was no noteworthy change on the level of fatigue presented by the users neither on how much they reported to like the technique.


(a) (b)

Figure 18 – (a) Example of a collaborative manipulation of a virtual car hood and (b) example of configuration of the RTD-4 for manipulating a virtual chair

Source: Aguerreche et al. [27].

2.5 Overview

This section presents an overview of the works described in the chapter. Table 1 compares the main aspects of the devices used in each work, which are composed by the location where the device is placed on the user's body, the number of devices used on each user and how the feedback is generated. Besides the device itself, it is interesting to compare the methodologies used for the user studies. In addition, Table 1 summarizes the following aspects of these tests:

- Number of participants;
- Number of tasks that each participant had to perform;
- Number of times each task was performed;
- Use of gravity in the environment;
- Accountability of physic effects;
- Existence of breaks between tasks: this indicates that users can rest in order to avoid fatigue;
- Application of a familiarization phase: this indicates that users can train how to use the system before doing the task;
- Collision detection: whether the system simulates collision with other objects or not, and, consequently, whether users were required to avoid collisions;

- Execution of a cognitive task during the test: this indicates that, during the test, users had to perform some other task to distract them;
- Whether there was a competition between the users or not;
- Use of a random scenario: this indicates that the scenario had random obstacles or that the manipulated object appeared in different locations, rotations, or shapes.

Table 1 – Comparison of experiment designs

Paper	Type of Feedback	Location	Quantity	# of participants	# of Tasks	Each task # times	Gravity	Physics	Break between tasks	Familiarization phase	Collision Detection	Cognitive Task	Competition	Random Order
Bloomfield et al. [15]	V	*	*	42	4	6				X	X			
An et al. [16]	V	A	1	6	1	160		X				X		X
M. Walker et al. [17]	V	A	1	23	4	48	X	X		X				
Niinimäki et al. [19]	VA	h	1											
Moehring et al. [20]	***	F	3	12	12	36				X	X			
Salzmann et al. [26]	P	h	1	20										
Aguerreche et al. [27]	P	h	1	24	3	20				X				
Han et al. [25]	**	F	1	10							X			
Giannopoulos et al. [22]	V	h	14	2	2	5					X			
Hummel et al. [23]	V	F	1	19	3	17		X	X	X			X	
S. Pamungkas et al. [24]	V	h	1	3	3	2				X	X			
Pacchierotti et al. [21]	**	F	1	7				X			X			

P: Passive Feedback, V: Vibrotactile, A: Audio
h: Hand, F: Finger, W: Waist, C: Chest, H: Head, A: Arm
* 8 on the hand, 12 on the arm – Figure 11 (a) and (b)
** own device, explained on the text
*** used vibrotactile or pressure device

3 Interaction Design: Proposed Technique

This chapter describes the haptic technique proposed in this work to help the user during the collaborative manipulation task.

As mentioned before, using the SkeweR technique, as far as the user moves his hand apart from the initial position of the crushing point, more difficult the collaborative interaction becomes. Based on this premise, the main idea of the technique is to signal to the user, by applying a vibratory feedback, whenever this situation happens.

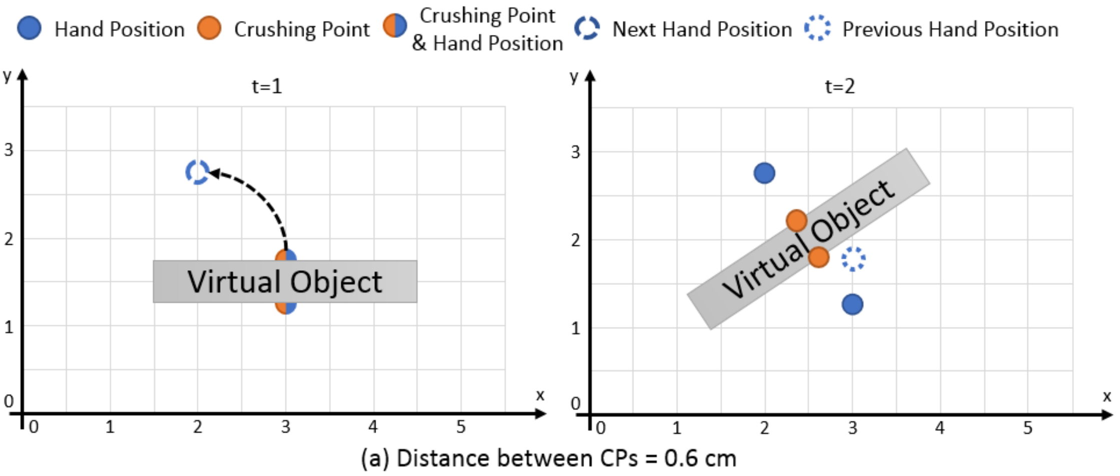
By adding the vibratory feedback, the following is expected:

- The time to complete a manipulation task will be lower than without any feedback;
- The number of collisions of the manipulated object with other objects will be smaller;
- Users will keep holding the object in the same position, as in real object manipulation.

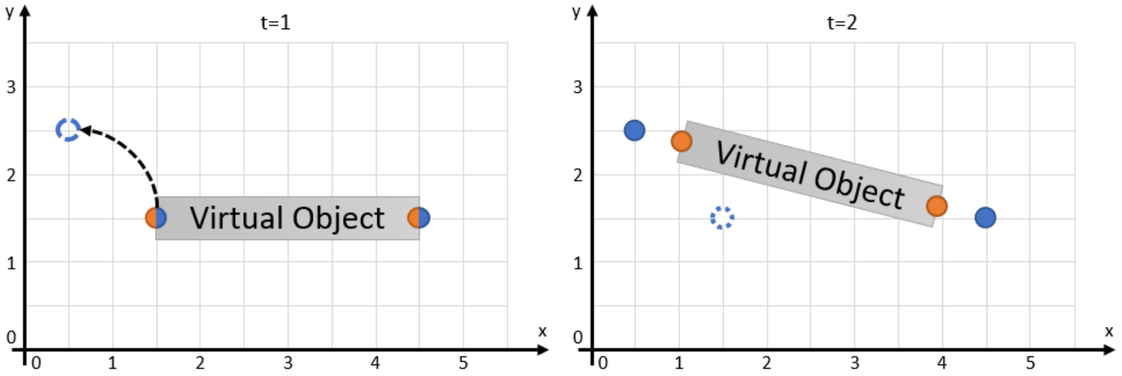
For interacting with an object, the user holds a tracking device used to point, select and move the object. Attached to this tracker has been installed a vibration motor that generates the haptic feedback to the user.

When the user touches the object surface and selects it for manipulation, the technique saves the position of this selection, named Crushing Point (CP) and starts tracking the subsequent users' movements. If during the manipulation, the distance between the hand and the CP becomes larger than a threshold, an event named **Apart Event** is recorded and the vibration motor starts vibrating.

Initially, this threshold was set a fixed distance between the CP and the position of the user's hand (HP). However, the amplitude of the rotations produced over an object by the HP, when using Skewer, depends on the distance between the CPs. As the examples presented in Figure 19 show, the rotations produced by the HP movement are inversely proportional to such distance. In both cases in Figure 19, a HP was moved 1 cm up and 1 cm into left. For Figure 19 (a), where the CPs are near to each other, a rotation of 34 degrees is produced by Skewer. On the other hand, on the case of Figure 19 (b), where the CPs are far from each other, the rotation produced by Skewer is just 14 degrees. Note that in the initial state(t=1), the CP and HP are in the same position, for both situation.



(a) Distance between CPs = 0.6 cm



(b) Distance between CPs = 3 cm

Figure 19 – Examples of object rotation based on different distances between CPs, after a HP movement.

Source: Author (2017).

Figure 20 shows the behaviour of the rotation amplitude as different distances between CPs are set. The horizontal axis shows different displacements of user’s HP.

Hence, if a fixed limit to generate apart events is used, in cases in which CPs are far from each other, unncessary signalization events would be generated. On the other hand, in cases in which CPs are set close together, movements that generate considerable rotations would not generate any signalization.

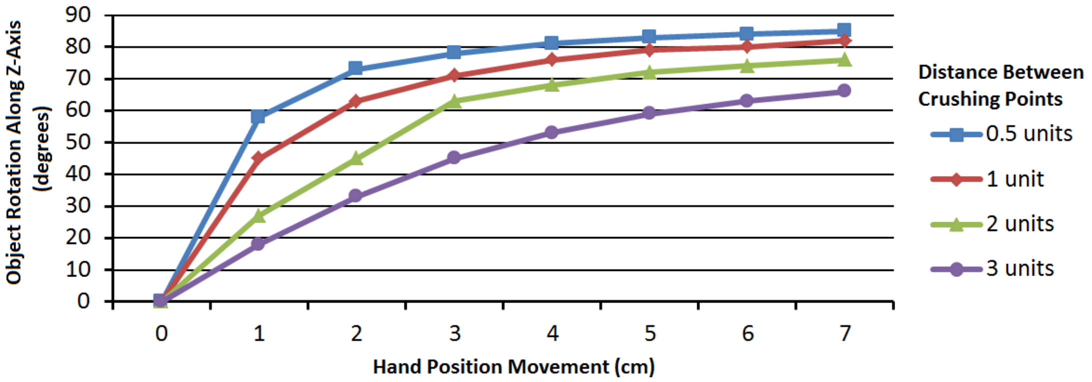


Figure 20 – Comparison of the Object Rotation by a HP movement.
Source: Author (2017).

For this reason, we choose to consider the distance limit to generate Apart Events, as a function of the distances between the CPs. Equation 5 shows how this threshold is calculated. In this equation HP1 and HP2 are the current users' hand position and CP1 and CP2 are que original CPs positions when the collaboration started.

$$r = \frac{d(HP_1, HP_2)}{d(CP_1, CP_2)} \qquad 5$$

HP_n– User *n* Hand Position
CP_n – User *n* Crushing Point
d(a, b) = distance between points a and b

From this equation, whenever the distance between the users' HPs is greater or less than 30% (0.7 > r > 1.3) from the distance of the users' CPs, a new Apart Event is recorded.

This value was empirically set by executing manipulation tests using thresholds of 10%, 20%, 30% 40% and 50%. The tests have shown that using values lower than 30% of the distance, results that a new Apart Event was generated too often, while higher values only produce Apart Events when the distance between hand position and the crushing point gets very high. Equation 6 describes the conditions for record a new Apart Event.

$$Apart\ Event(r = ratio) = \begin{cases} r > 1.3, & Apart\ Event \\ 0.7 < r < 1.3, & not\ a\ Apart\ Event \\ r < 0.7, & Apart\ Event \end{cases} \qquad 6$$

When a new Apart Event is generated, a continuous vibration signal is activated, and its intensity varies proportionally to the ratio calculated on equation

5. Figure 21 shows the intensity variation (amplitude) of the vibration motors, based on the ratio.

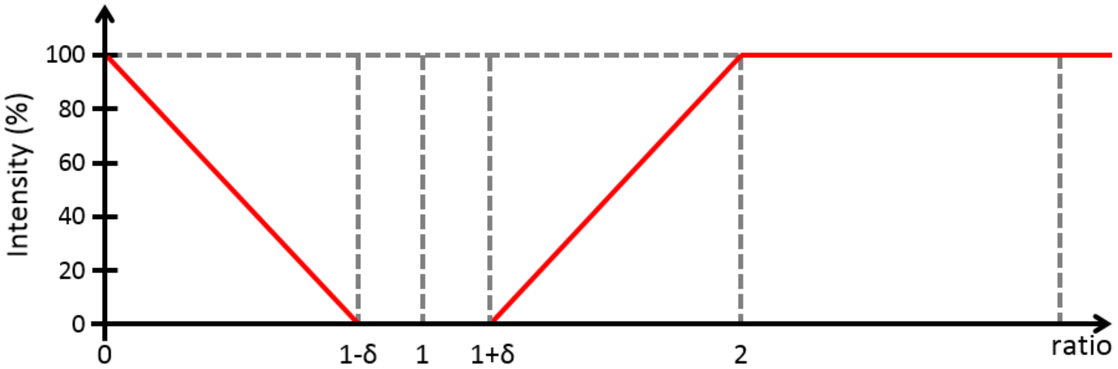


Figure 21 – Vibration intensity based on the ratio between the distances of the HPs and the CPs.

Source: Author (2017).

4 Experiment Design

This chapter presents how the proposed technique was modeled and tested. First, the idea of the experiment is presented. After that, the real and virtual setups are described, followed by the detailing of the approaches used in the experiment to test the proposed technique. At the end, the hardware used is described.

The experiment consists on a simple task; to accomplish it, two users had to manipulate together a virtual object, translating and rotating it through a virtual wire course. Figure 22 shows the virtual environment presented to the users. The environment had a straight wire course in its middle and six obstacles along the wire's length.

A simple straight wire was used as a result of the preliminary tests, which had a more complex wire course. The environment that presented the complex wire course got users confused in what regarded the depth of the environment; this confusion was due to a monoscopic screen.

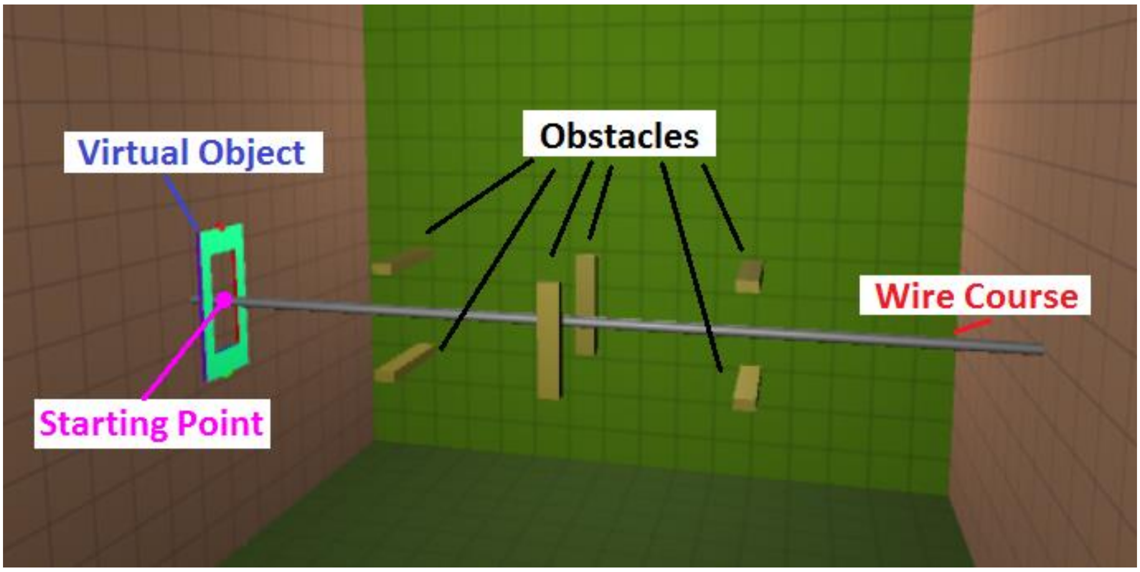


Figure 22 – Virtual Environment used in the experiment

Source: Author (2017).

During the task, the users had to move a virtual square ring along the wire without touching it. The starting point of the trajectory was always the same end of the wire course, with the virtual object placed in a position free of collisions. Along the wire course, obstacles were used to force the users to rotate the virtual object, while any collision feedback was generated. Each user was looking at the wire course from opposite sides of the box, as they were in the real-world setup.

In the virtual environment, the hand of each user was represented by a virtual sphere used to select the crushing point from where the user wanted to move the object. Once the hand representation touched the object, the sphere changed its color, to signal the user that he could select the object. Object selections were performed by pressing a button attached to the tracker. Once both users had grabbed the virtual object, they were able to move it to the other side of the wire (destination). As soon as the object reached its destination, the object's position/orientation was reset to the initial position/orientation, and a new trial would begin.

As mentioned before, while the users were performing a cooperative manipulation using the SkeweR technique, due to the lack of any physical constraint, the hand position could be moved to a different position from the initial position of the hand point. So, in this experiment, after grabbing the object, the users were asked to keep the pointer as close as possible to the original position of the crushing point on the object's surface. In order to help the users in this task, three different approaches were used: visual feedback (VF) and tactile feedback (TF). Also, no feedback (NF) was used as a reference approach. The operation of these modalities is described in the next section.

During the experiment, users sat in opposite sides of a table holding a magnetic tracking device, with 3DOF for translation, in their dominant hands. There was an individual 23" LCD screen for each user to visualize the virtual environment in a first-person viewpoint. Figure 23 shows the real setup; the monitors were not in front of the users because they disturbed the magnetic tracker device.

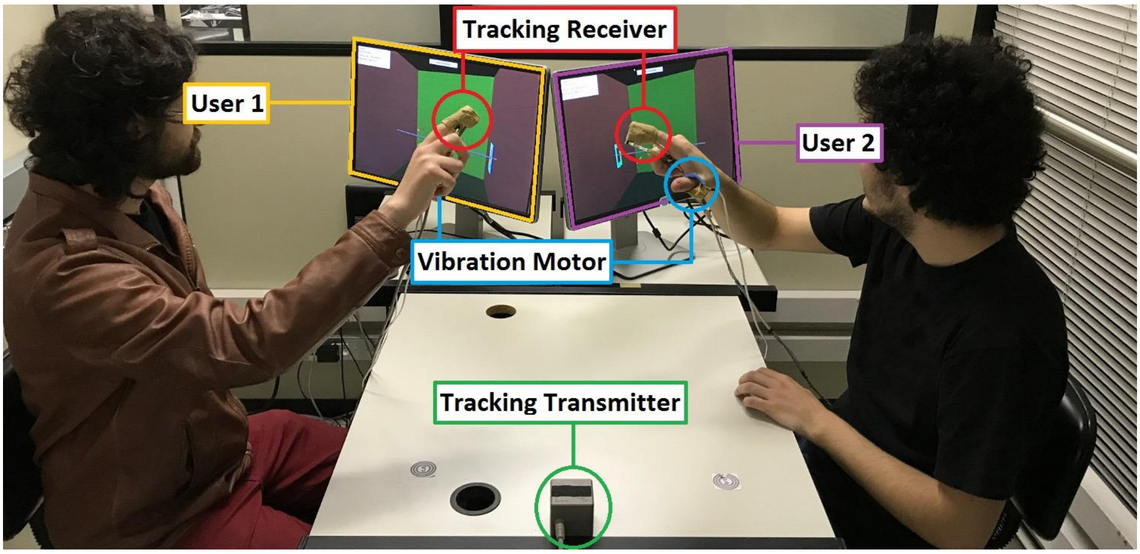


Figure 23 – Real experiment setup

Source: Author (2017).

4.1 Feedback Modalities

After object selection, a small sphere on the virtual object’s surface indicated the original crushing point for each user, as shows the first image of Figure 24. To avoid confusion, a distinct color was assigned to the sphere of each user.

In order to help users keep their hands near to the original crushing point, three different feedback modalities were tested. The first generated **no feedback**. The second used **visual feedback**, which showed a line between the crushing point and the user’s hand position. The line would appear when the distance between the crushing point and the user’s hand position exceeded a threshold. Additionally, the users’ hand position blinks (Figure 24).

The third approach, the **tactile feedback**, produced vibrations on the users’ finger when the distance between the current tracker position (HP) exceeded the threashold (30%) of the distance between the Crushing Poins. and the original crushing point. The vibration intensity (amplitude) was linearly proportional to the distance between these two points. The vibration frequency was the same throughout the test. None of these modalities gives any feedback when the object collides with an obstacle or with the wire.

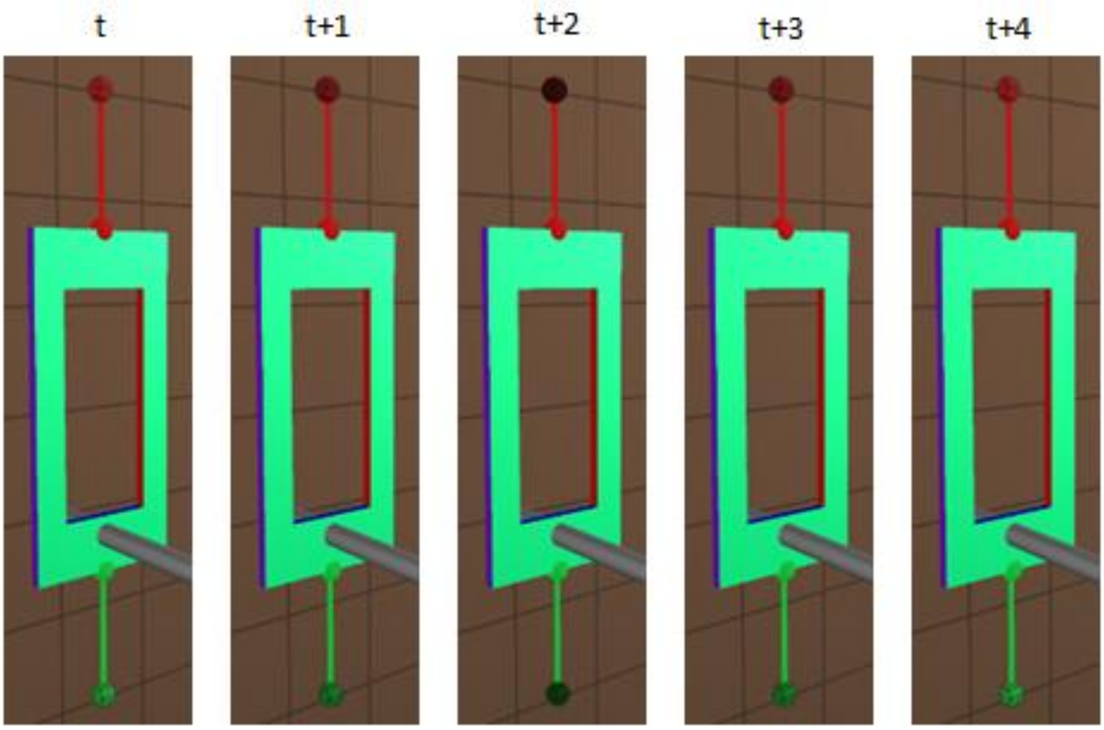


Figure 24 – Example of Visual Feedback

Source: Author (2017).

4.2 Haptic Hardware

In order to enable haptic feedback during the experiment, each participant had to wear a haptic device and a tracking device in his dominant hand.

The haptic device was built (Appendix A) with an Eccentric Rotation Mass (ERM) vibration micromotor attached to the thumb of each user with a Velcro strap (Figure 25). An Arduino Nano board controlled each vibration motor using two Pulse-Width Modulator (PWM) ports. PWM is a category of voltage regulator that makes it possible to control the output voltage [28]. Therefore, it was possible to control the vibration intensity of each vibration motor separately. A host PC powered the Arduino Nano board and handled the intensity of each vibration motor via USB connection.

A Polhemus Fastrak© was used to track the index finger position of each user. Attached to each of these trackers there was a button used to select and hold the virtual object.

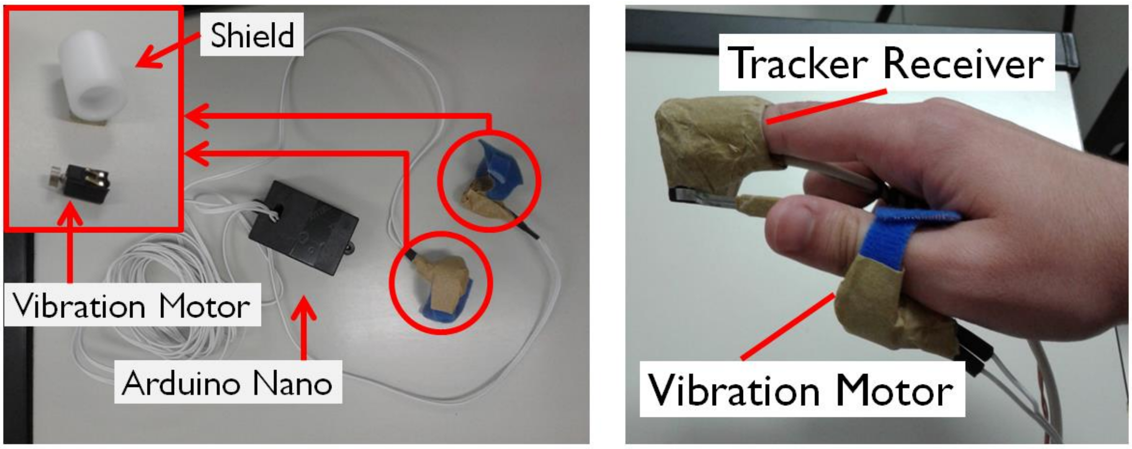


Figure 25 – Tactile device

Source: Author (2017).

5 Experiment Protocol

This chapter describes how the experiment was conducted and presents the demographics of the users.

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

Two questionnaires were filled in by each participant: before the start of the experiment, they were asked to answer a questionnaire about their background (Appendix C) and, after the experiment was completed, they were asked to answer a questionnaire about the experience (Appendix D). The experiment itself was divided into two phases: a training phase and the trial phase.

In the first phase, the observer explained the concept of the SkeweR technique and the goal of the three 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, as well as avoid collisions between the object and the obstacles. After these instructions, the pairs had up to 2 minutes to train how to collaboratively manipulate the virtual object. In order to achieve a higher level of coordination, users were advised to communicate with each other verbally during both the training period and the trials. The verbal communication was recorded for subsequent analysis.

In the second phase, the pairs were instructed to perform as many trials as possible in 15 minutes by collaboratively moving the object from the beginning to the end of the wire course. The users had a 1 minute and 30 seconds break in the middle of the experiment.

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. Each group of NF, VF and TF was considered a block. For evaluation purposes and to reduce the order effect, the first feedback modality was different for each of the three pairs in a balanced order, as shown in Figure 26.

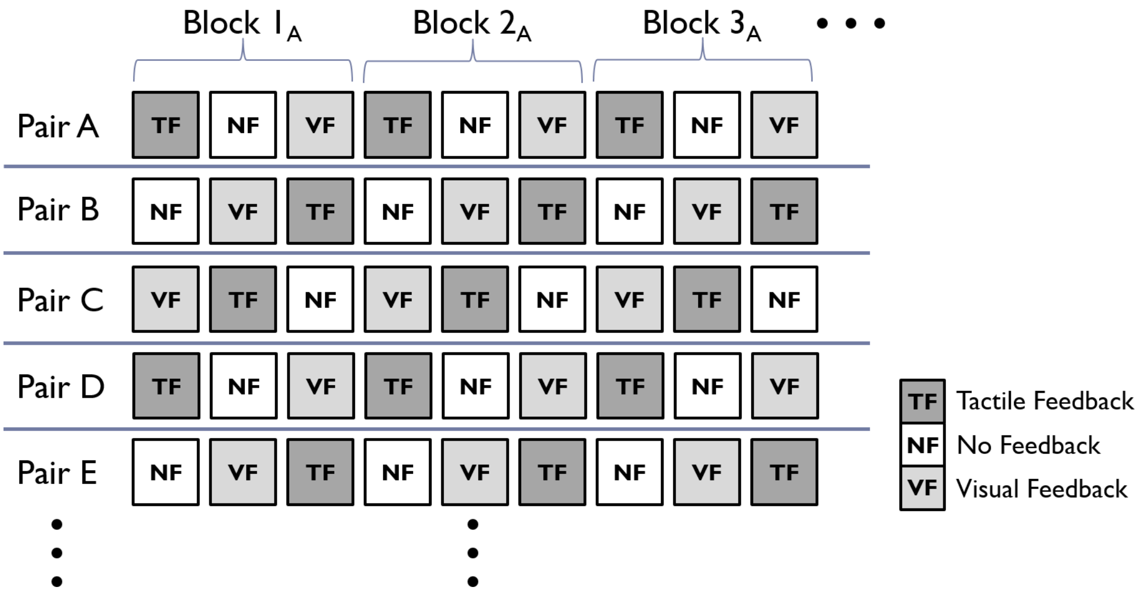


Figure 26 – Example of balanced order trials

Source: Author (2017).

Table 2 compares the related work with the proposed technique.

Table 2 – Comparison of experiment designs with Proposed Technique.

Paper	Type of Feedback	Location	Quantity	# of participants	# of Tasks	Each task # times	Gravity	Physics	Break between tasks	Familiarization phase	Collision Detection	Cognitive Task	Competition	Random Order
Bloomfield et al. [15]	V	*	*	42	4	6				X	X			
An et al. [16]	V	A	1	6	1	160		X				X		X
M. Walker et al. [17]	V	A	1	23	4	48	X	X		X				
Niinimäki et al. [19]	VA	h	1											
Moehring et al. [20]	***	F	3	12	12	36				X	X			
Salzmann et al. [26]	P	h	1	20										
Aguerreche et al. [27]	P	h	1	24	3	20				X				
Han et al. [25]	**	F	1	10							X			
Giannopoulos et al. [22]	V	h	14	2	2	5					X			
Hummel et al. [23]	V	F	1	19	3	17		X	X	X			X	
S. Pamungkas et al. [24]	V	h	1	3	3	2				X	X			
Pacchierotti et al. [21]	**	F	1	7				X			X			
Proposed technique	**V**	**h**	**1**	**42**	**1**	**22.6**			**X**	**X**				

P: Passive Feedback, V: Vibrotactile, A: Audio
h: Hand, F: Finger, W: Waist, C: Chest, H: Head, A: Arm
* 8 on the hand, 12 on the arm – Figure 11 (a) and (b)
** own device, explained on the text
*** used vibrotactile or pressure device

5.1 Participants

The experiment was executed by 23 pairs. Among these, the first two pairs were considered pilot tests. It was requested of the pilot pairs that they executed 30 trials. One pair spent 30 and the other 20 minutes to complete the test. After the experiment, the pilot testers filled in the experiment questionnaire, whose second question was: What did you think about of the duration of the task? One user answered “Ideal”, two answered “Long” and one answered “Very Long”. Still regarding the length of the test, the first pair expressed fatigue 24 minutes after having started. The observer asked if they wished to stop the test, but the users preferred to continue. The other pair reported fatigue after the end of the experiment. Thus, a time limit of 15 minutes was set for the entire test to avoid fatigue.

The average age of the pairs (21 pairs or 42 users in total) was 25.66 years (σ^2 = 5.65). 33 of the participants were men and 8 were women, 1 participant skipped this question. Right-handed users represented 85.71% of the total number of participants, while 11.9% were left-handed and 1 user declared himself as ambidextrous. Figure 27 shows other statistics regarding the users’ profile.

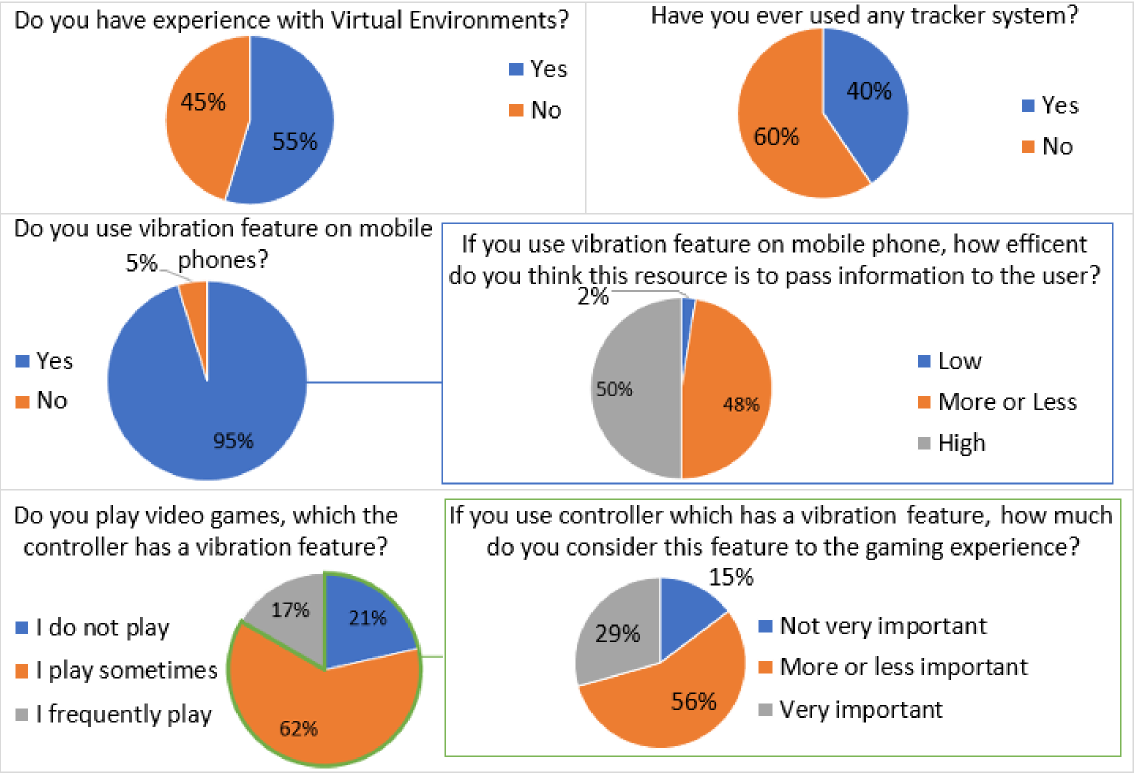


Figure 27 – Characterization Questionnaire

Source: Author (2017).

6 Experiment Results and Discussion

This chapter presents the quantitative metrics used to evaluate the proposed technique and their results, as well as the qualitative questions and results realized after the experiment.

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

6.1 Quantitative Results

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

- time spent to finish each trial;
- number of times the hand position moved away from the crushing point;
- amount of time in which the hand position remained apart from the crushing point;
- average distance between the crushing point and the hand position;
- number of collisions between the manipulated objects and the obstacles.

Figure 28 shows the distribution of the time spent to finish all trials (first metric) based on the modality used. Considering each type of feedback, the average time to complete a trial was greater when using TF than with NF or VF (Table 3). A one-way ANOVA, where $F_{2,471} = 3.690$, $p<.026$, showed that these differences between modalities are significant. The boxplot in Figure 29 illustrates the differences between the modalities; the circles represent the mean of each feedback, and the x's are the outliers. Outliers represent completion time that was too different from the median.

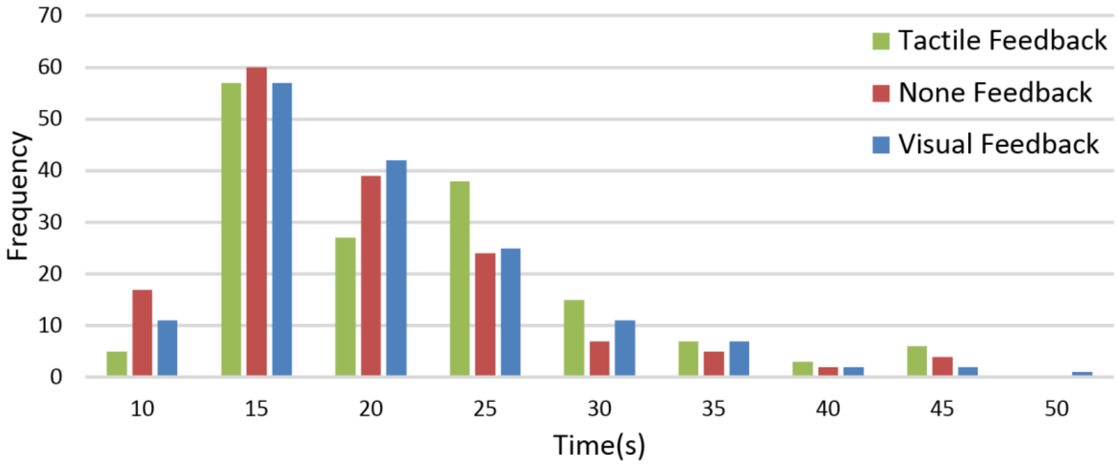


Figure 28 – Histogram of completion time for each type of feedback.

Source: Author (2017).

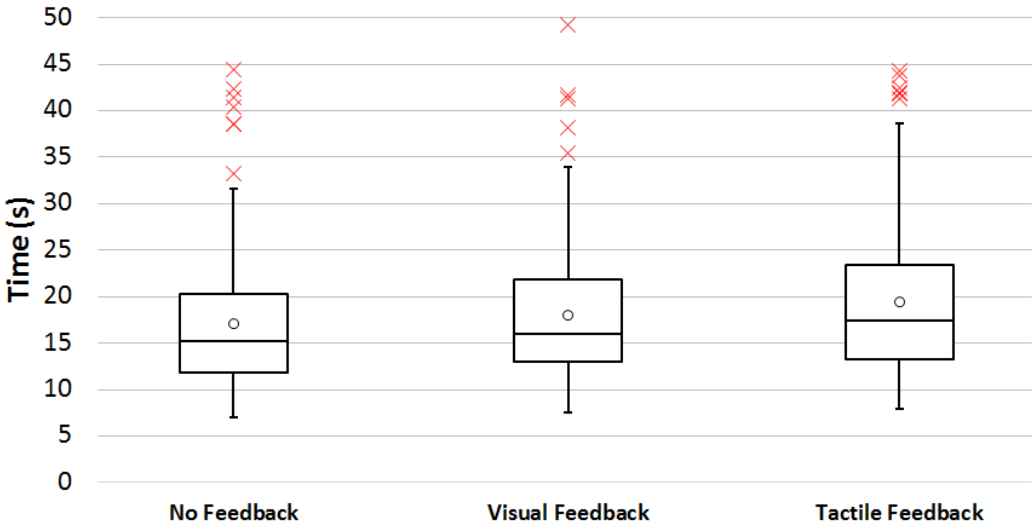


Figure 29 – Boxplot of completion time for each type of feedback.

Source: Author (2017).

Table 3 – Average time to complete a trial.

Feedback	Average (s)	σ^2(s)
None	18.73	7.25
Visual	19.61	6.61
Tactile	21.12	7.41

Comparing the modalities two by two, a t-test indicated that there was no significant difference between VF-NF or TF-VF. However, the difference between TF-NF was statistically significant ($p<.008$) (Table 4).

Table 4 – Table of p in t-test between groups.

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

The second metric computed the number of times the hand position moved away from the crushing point. This is called an apart event, which happens whenever the distance between the hand and the crushing point is larger than a threshold. To register a new apart event, the hand has to move back to a distance smaller than the threshold. Table 5 shows the results for this metric.

It is possible to see that trials with tactile feedback had higher numbers of apart events. Figure 30 shows the distribution of these events for each condition.

Table 5 – Average number of apart events during trials by group.

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

A one-way ANOVA, where $F_{2,60}=7.59$, $p<.001$, showed that the differences between modalities were significant. Comparing the modalities two by two, a t-test indicated that there was no significant difference between NF-VF, but the difference between TF-VF and TF-NF was statistically significant (Table 6).

Table 6 – Table of 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

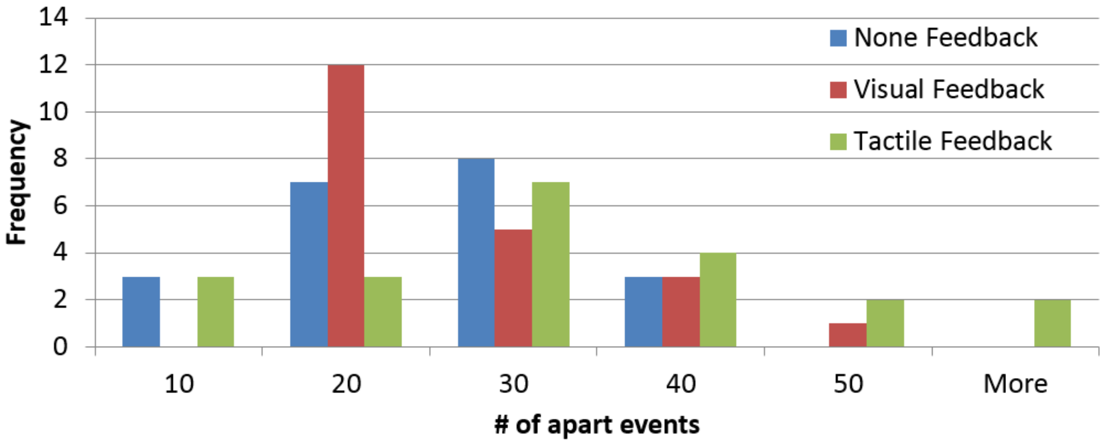


Figure 30 – Histogram of the number of apart events by trial.
Source: Author (2017).

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 7 shows the results of this metric for each condition. Tactile feedback presented smaller duration of apart events in comparison to the other two modalities. This indicates that, by using tactile feedback, users can be aware of wrong hand positions more easily than when using visual or no feedback.

Table 7 – 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, where $F_{2,1491}$=25.942, p<.0001, showed that the differences between modalities were significant. Figure 31 shows the distribution of apart events for each condition. The graph shows that tactile feedback trials presented shorter events in comparison to the other two conditions. Comparing the modalities two by two, a t-test indicated that there was no significant difference between VF-NF. However, the difference between VF-TF and NF-TF was significant (Table 8).

Table 8 – p in t-test betwee 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

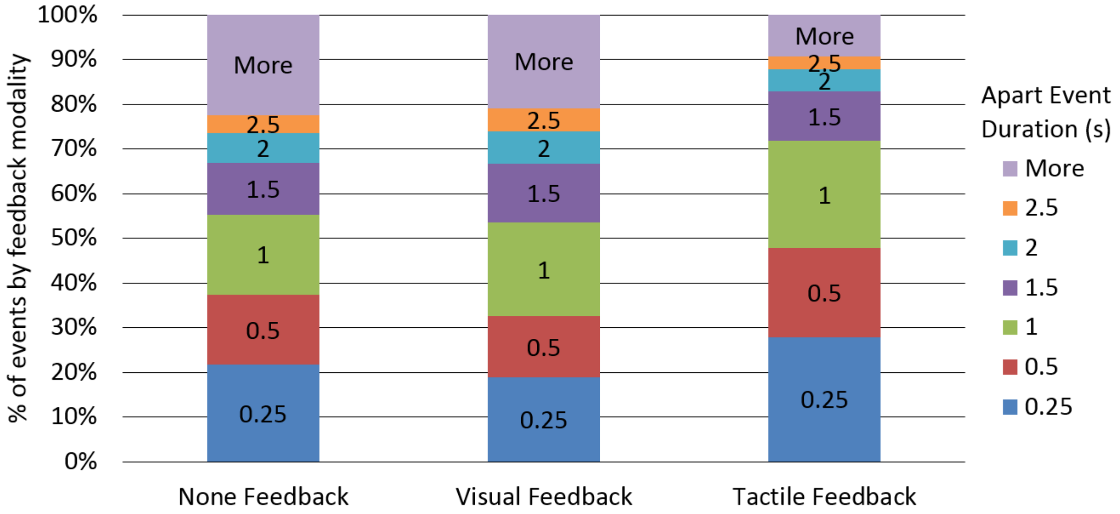


Figure 31 – Histogram of the duration of apart events.
Source: Author (2017).

In order to evaluate the existence of a learning effect along the trials, the duration of apart events was analyzed. Figure 32 shows the average duration of apart event in each trial. Despite of the line apparent to reduce the average amplitude of Apart Event in each trial, the coefficient of determination R^2 shows that there is no relationship between the Apart Event and the passing of time (NF-$R^2 = 0.464$, VF-$R^2 = 0.043$, and TF-$R^2 = 0.410$).

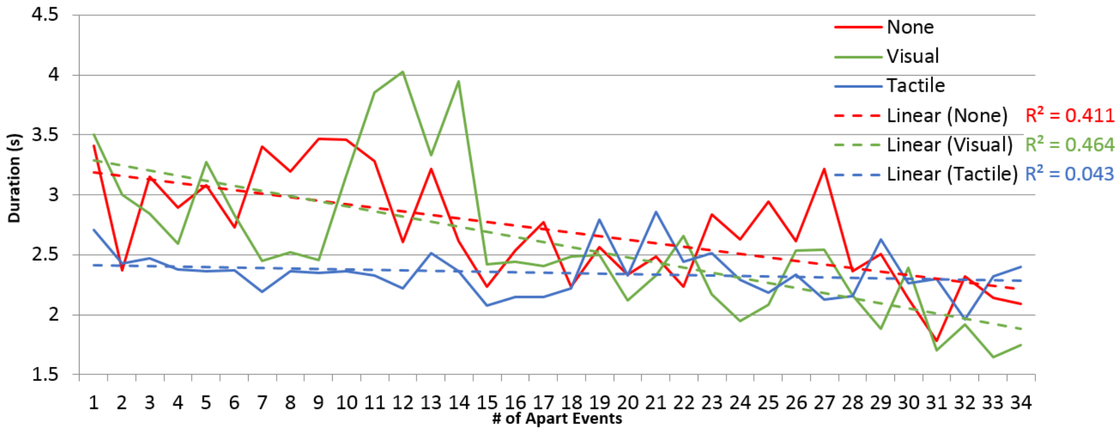


Figure 32 – Average time of apart events.
Source: Author (2017).

The fourth metric represents the average distance between the crushing point and the hand position. This distance was found smaller when using tactile feedback, if compared to the other two modalities. Thus, users can keep their hands in a more natural position. Table 9 shows the results of this metric.

Table 9 – 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

The one-way ANOVA test showed that the difference between the modalities was statistically significant, where $F_{2,1491}=16.507$, $p<.0001$. After the ANOVA, a t-test was performed to verify if the difference between groups of feedback was significant. Table 10 shows that there was no significant difference between VF-NF. However, there was a significant difference between TF-NF and TF-VF.

Table 10 – Table of p in t-test between groups in terms of absolute difference.

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

Figure 33 shows the distribution of these distances classified by type of feedback. The graph shows that tactile feedback trials had less events with mean distance higher than 3.25 cm. For this condition, most of the mean distances found were of around 2.25 cm.

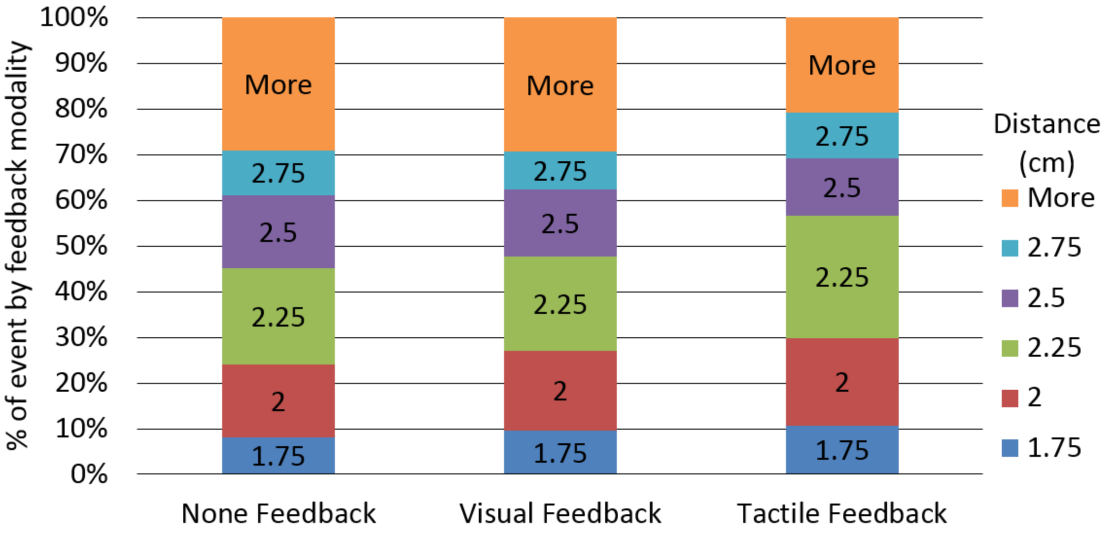


Figure 33 – Histogram of the absolute difference between crushing point and hand position.

Source: Author (2017).

The last metric analyzed the number of collisions between the ring and the obstacles and wire of the scene. The percentage of collisions with the obstacles or wire during the task was similar between the three types of feedback modalities (Table 10). The one-way ANOVA test, where $F^{(Obs)}{}_{2,60} = 0.091$, $p^{(Obs)} < .91$ and $F^{(Wire)}{}_{2,60} = 0.199$, $p^{(Wire)} <.82$, indicated that the differences between modalities were not significant. A possible explanation for this result is the fact that the task did not generate any penalty when the users collided with an obstacle or the wire, so they were not worried about avoiding them.

Table 11 – Comparison of the mean collision number between feedback modalities.

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

6.2 Qualitative Results

After the experiment, the users were asked to fill a questionnaire about the experiment individually. There were two questions related to the experiment setup: How uncomfortable was wearing the Velcro strap with vibration motor to you? (Q1), which 47.5% answered nothing, 47.6% some, and 4.8% a lot. The second question was: How do you feel about the experiment time length? The answers were: 4.8% Short, 40.5% Idel, 52.4% Long, and 2.3% Very Long. Also, there were 7 other questions related to the manipulation technique. The questions and answers are shown in Table 12 and Table 13. The significance of the results obtained from the qualitative questions is shown in the boxplots of Figure 34. To plot this data, the answers were weighted (indicated between brackets in the figure). The circles are the mean of each question and the x’s are its outliers. In this case, the outliers represent strong differences in the opinion of the users in comparison to the median answer.

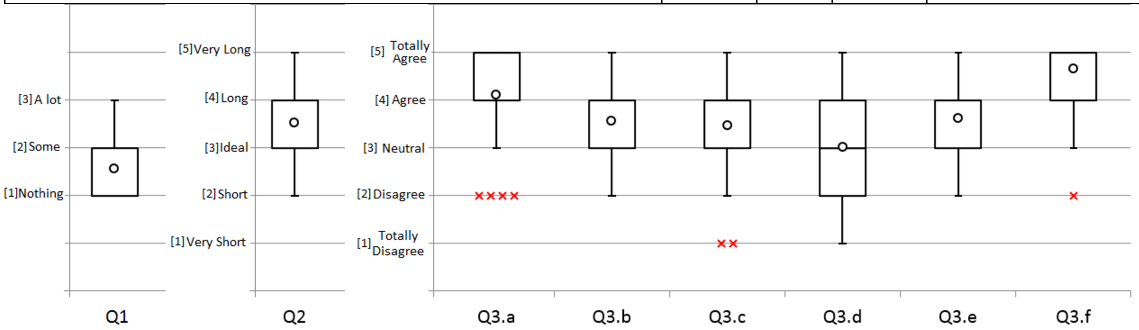
Table 12 – Questions Q3. (%).

	Question	TD	D	N	A	TA
a	I thought the Skewer technique 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 take 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 take 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 take 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; TA: Totally Agree.

Table 13 – Question 4 (%).

	NF	VF	TF	Not Answered
Q4: Which of the three feedback modalities did you prefer to use?	0	9,5	88,1	2,4



circles: mean; cross: outliers.

Figure 34 – Boxplot of the Qualitative Questionnaire.

Source: Author (2017).

Question 1 shows that more than 50% of the users felt some sort of discomfort using the vibration motor. However, in Questions 3 and 4, it is possible to notice that most of the participants preferred to use tactile feedback to correct the tracker position Table 12 (d, e, f) and Table 13. In addition, by analyzing subjects' comments (Appendix E) made after the experiment, it is possible to perceive that, frequently, when using VF and NF conditions, subjects were not aware whether their hand position was correct or not, or forgot to adjust their HP. On the other hand, it is clear from the answers that, with TF, it became easy to perceive that there was an issue that should be corrected.

These comments can also explain why the number of apart events (2nd metric; Table 5) was higher with tactile feedback than with other feedback modalities, but the duration (3rd metric; Table 7) and absolute distance (4th metrics; Table 9Table 9) were lower than the other feedback modalities. Because tactile feedback is easily perceivable, even in an eyes-off interaction, as soon as the users took notice of the feedback, they would try to correct their positions, while with no feedback or visual feedback, it could take a while for them to perceive that they were not touching the surface of the virtual object.

Furthermore, when analyzing the comments from the questionnaire and the talk recorded during the task, it is possible to understand 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 using the technique during the experiment (Table 12, questions a, b and c); however, most of them felt that the experiment took too long (question 2).

Appendix E shows all users’ comments given during and after the experiment. The majority of the comments complain about the experiment duration, some of the users thought that the experiment was funny and others did not. Some of them found it difficult to synchronize their movements with their partner’s. And one of the users found it hard to understand the environment without the stereoscopic vision.

7 Conclusion and Future work

This work proposes the use of a haptic feedback technique to improve the experience of collaborative manipulation. The SkeweR technique was used as a test bed and modified to include tactile feedback to signal the users when they are not properly interacting with the object.

To validate the technique, a set of trials, in which each pair of users had to grab and move together a virtual object through a virtual path, was run. Users wore a tracking system to map their hand movements to the virtual environment. To generate the haptic feedback, a haptic device was built using a vibrotactile motor.

For evaluation purposes, three distinct types of feedback (no feedback, visual feedback and haptic feedback) were applied to the chosen interaction technique and compared.

The results show that the use of visual or haptic feedback makes no significant difference on task completion time. There was also no noteworthy difference in the number of collision events between the three feedback techniques, contrary to what was expected. The use of a monoscopic screen might have caused this problem, given that many users complained of not being able to see the obstacles properly. Thus, the first hypothesis was disproved (H1: when users use haptic feedback, they perform more coordinated manipulations, and, as a consequence, the number of collisions between the object and the scenario decreases).

However, the time of each apart event was smaller when using haptic feedback, in opposition to using visual or no feedback, since it made it easier for users to notice any incorrect position. The distance between the crushing point and the hand position was also smaller with the use of haptic feedback, in comparison with trials with visual or no feedback, since it made it possible for users to easily notice the incorrect position. Hardly ever did the distance grow a lot, thus we accept the second hypothesis (H2: when users use haptic feedback, it is easier for them to be aware of unnatural hand positions).

Together with the quantitative metrics, the qualitative questionnaire indicates that the users preferred using haptic feedback to using the other feedback modalities when it came to being aware of wrong actions. Users complained that the other feedback modalities made it difficult for them to understand that they were performing a wrong movement.

An important development of this work would be to implement a version of the test with stereoscopic screen, which could provide better results to analyze collision metrics. The research is also headed in the direction of building a glove with an array of vibrotactile motors that inform which direction each user has to move his hand to keep it on the crushing point. In addition, a passive haptic feedback technique can be used as reference.

Regarding the experiment protocol, reducing the overall time of the experiment to 10 minutes is advised in order to reduce users' fatigue. Making the experiment a competition between the users would also be an improvement, a way to motivate the participants and generate a better performance when manipulating the virtual object.

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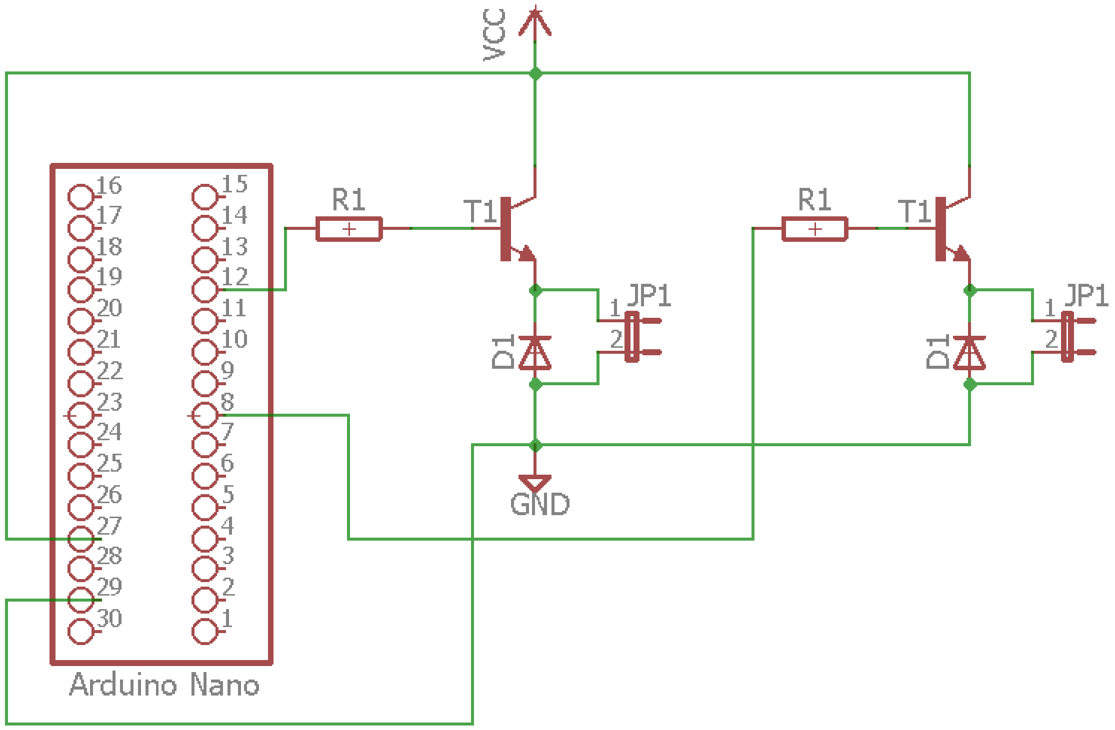
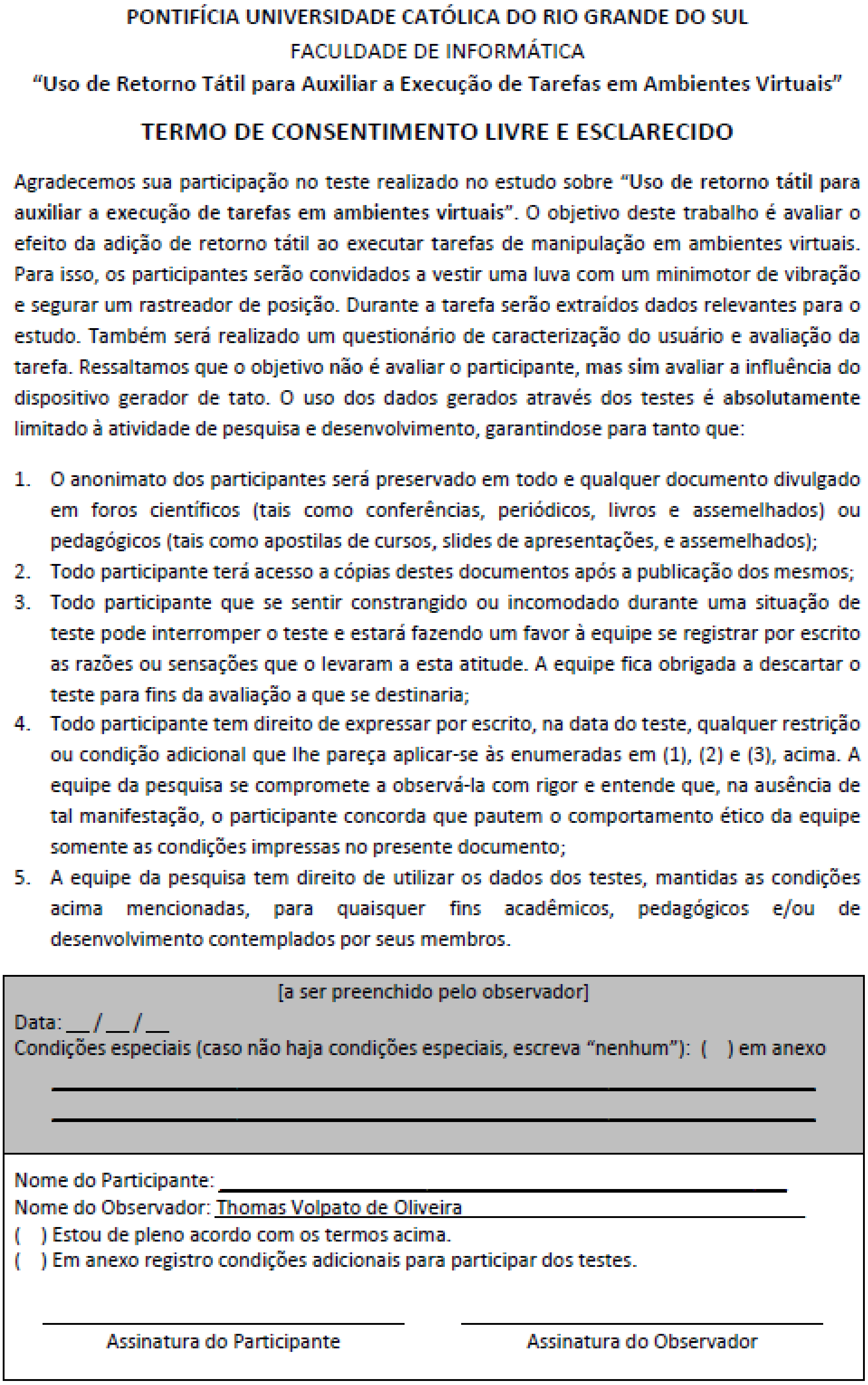
Appendix A – Hardware Design



Name	Component
R1	1K ohm
T1	BC556
D1	N4007
JP1	Vibration motor 5v

Appendix B – Informed Consent Form



PONTIFÍCIA UNIVERSIDADE CATÓLICA DO RIO GRANDE DO SUL
FACULDADE DE INFORMÁTICA
"Uso de Retorno Tátil para Auxiliar a Execução de Tarefas em Ambientes Virtuais"

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Agradecemos sua participação no teste realizado no estudo sobre **"Uso de retorno tátil para auxiliar a execução de tarefas em ambientes virtuais"**. O objetivo deste trabalho é avaliar o efeito da adição de retorno tátil ao executar tarefas de manipulação em ambientes virtuais. Para isso, os participantes serão convidados a vestir uma luva com um minimotor de vibração e segurar um rastreador de posição. Durante a tarefa serão extraídos dados relevantes para o estudo. Também será realizado um questionário de caracterização do usuário e avaliação da tarefa. Ressaltamos que o objetivo não é avaliar o participante, mas sim avaliar a influência do dispositivo gerador de tato. O uso dos dados gerados através dos testes é absolutamente limitado à atividade de pesquisa e desenvolvimento, garantindose para tanto que:

1. O anonimato dos participantes será preservado em todo e qualquer documento divulgado em foros científicos (tais como conferências, periódicos, livros e assemelhados) ou pedagógicos (tais como apostilas de cursos, slides de apresentações, e assemelhados);
2. Todo participante terá acesso a cópias destes documentos após a publicação dos mesmos;
3. Todo participante que se sentir constrangido ou incomodado durante uma situação de teste pode interromper o teste e estará fazendo um favor à equipe se registrar por escrito as razões ou sensações que o levaram a esta atitude. A equipe fica obrigada a descartar o teste para fins da avaliação a que se destinaria;
4. Todo participante tem direito de expressar por escrito, na data do teste, qualquer restrição ou condição adicional que lhe pareça aplicar-se às enumeradas em (1), (2) e (3), acima. A equipe da pesquisa se compromete a observá-la com rigor e entende que, na ausência de tal manifestação, o participante concorda que pautem o comportamento ético da equipe somente as condições impressas no presente documento;
5. A equipe da pesquisa tem direito de utilizar os dados dos testes, mantidas as condições acima mencionadas, para quaisquer fins acadêmicos, pedagógicos e/ou de desenvolvimento contemplados por seus membros.

[a ser preenchido pelo observador]

Data: __/__/__

Condições especiais (caso não haja condições especiais, escreva "nenhum"): ( ) em anexo

____

____

Nome do Participante: ________________________________

Nome do Observador: Thomas Volpato de Oliveira

( ) Estou de pleno acordo com os termos acima.

( ) Em anexo registro condições adicionais para participar dos testes.

____________________	____________________
Assinatura do Participante	Assinatura do Observador

Appendix C – User characterization questionnaire

This questionnaire was developed in Google Forms.

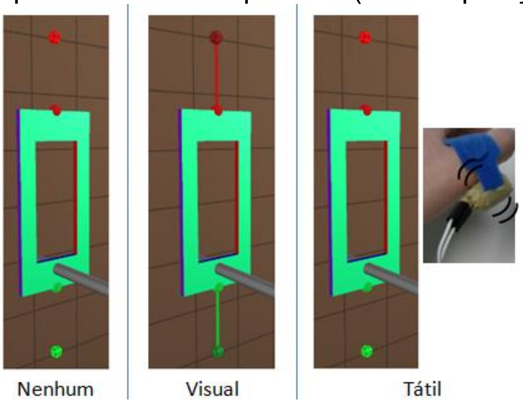
Nome:	
Idade*:	
Gênero:	( ) Masculino ( ) Feminino ( ) Prefiro não dizer ( ) Outro:
Nível de Escolaridade:	( ) Ensino Fundamental ( ) Ensino Médio ( ) Ensino Superior (em andamento) ( ) Ensino Superior (completo) ( ) Pós-Graduação (em andamento) ( ) Pós-Graduação (completo)
Apresenta algum tipo de daltonismo?*	
Qual sua mão dominante?*	( ) Direita ( ) Esquerda ( ) Direita e Esquerda
Tem experiência com Ambientes Virtuais? (Um ambiente 3D no qual é possível interagir com objetos do cenário ou simplesmente caminhar por um local. Ex: jogos virtuais em 1ª ou 3ª pessoa.)*	( ) Sim ( ) Não
Já utilizou previamente algum sistema de rastreamento de posição em ambientes virtuais? (Microsoft Kinect, Wiimote, PSmove, etc.)*	( ) Sim ( ) Não
Você utiliza o recurso de vibração do celular?*	( ) Sim ( ) Não
Caso utilize a vibração do celular, o quanto você acha eficiente este recurso para passar informações ao usuário?	( ) Pouco Eficiente ( ) Mais ou menos eficiente ( ) Muito Eficiente
Você joga videogames em que o controle possui recurso de vibração?*	( ) Não jogo ( ) Jogo às vezes ( ) Jogo frequentemente
Caso utilize controles de videogame com vibração, o quanto você considera este recurso importante para a experiência do jogo?	( ) Pouco importante ( ) Mais ou menos importante ( ) Muito importante

Appendix D – Task Evaluation Questionnaire

This questionnaire was developed in Google Forms.

Nome	
O quanto de desconforto você sentiu ao utilizar a presilha com o minimotor de vibração? *	( ) Nada ( ) Pouco ( ) Muito
O que você achou da duração da tarefa? *	( ) Muito Curta ( ) Curta ( ) Ideal ( ) Longa ( ) Muito Longa

Tipo retorno ao desprender (tirar da posição original) o rastreador do objeto



3. Dentre as afirmativas abaixo, indique o quanto você concorda com elas: *

	DT	D	ND	C	CT
Eu achei a técnica fácil de aprender.					
Eu pude facilmente mover o objeto para onde eu queria.					
Eu pude facilmente girar o objeto para a orientação que eu queria.					
Quando eu desprendi (tirei da posição original) minha mão do objeto, pude facilmente perceber isto sem nenhum retorno.					
Quando eu desprendi (tirei da posição original) minha mão do objeto, pude facilmente perceber isto com auxílio do retorno visual.					
Quando eu desprendi (tirei da posição original) minha mão do objeto, pude facilmente perceber com auxílio do retorno tátil.					

Comentário da tarefa: por favor, diga o que achou da tarefa e dê sugestões para futuras tarefas.	
Qual dos três tipos de retorno você achou melhor? *	( ) Sem nenhum ( ) Com visual ( ) Com vibração

DT: Discordo Totalmente D: Discordo: ND: Nem Concordo, Nem DiscordoC: Concorco CT: Concordo Totalmente.

Appendix E – Users' Comments

This appendix shows the users comments after the experiment.

User	Comment
2	Batuta Top, precisa de música
3	Foi mais fácil aproximar a mão do objeto novamente com o retorno tátil do que com as outras técnicas devido ao dizkonforrto da vibração. A tarefa em si não foi muito longa, mas causou estresse no braço.
4	Técnica complicada de utilizar. O uso do motor retira a atenção da tarefa.
5	Achei a proposta divertida
6	Divertido. Auxílio visual pouco perceptível.
8	Achei a tarefa interessante, pois permitiu a utilização e comparação de diferentes técnicas de percepção.
11	Além de fácil e clara, achei divertida também. Acredito que a melhor forma de perceber o quão distante estávamos do ponto original foi de fato a vibração. Era como um alerta. Sem a vibração, o meu objetivo era mover a peça corretamente (sem tocar nos objetos). Quando havia a vibração eu sentia vontade de fazer a tarefa corretamente, mantendo-me perto do ponto original além de mover o objeto de forma adequada.
13	Um pouco cansativo, mas divertido
14	Divertida, no final pode ser que as pessoas passem mais rapido por estarem cansados do teste. Cansa um pouco o braço
17	Interessante
18	Muito longa. Cansa muito o braço
19	A tarefa é um pouco difícil, mas por ter que coordenar com outra pessoa.
20	Tarefa interessante. Dificultando apenas por coordenação de duas pessoas e falta de prática.
21	Menos tempo de duração, cansa o braço.
23	Achei a tarefa interessante. Gostei de participar. E gostei da técnica que está sendo desenvolvida. O retorno tátil foi o mais útil para mim. Confesso que já estava um pouco cansada na segunda rodada. Gostaria de ter recebido algum tipo de feedback em caso de colisão com o arame. Acredito que, assim, eu teria me mantido mais atenta aos meus movimentos até o final do teste. Mas fui bem guiada pelo retorno tátil no que diz respeito a desprender a mão do objeto.
24	Bem elaborada para testar o controle do usuário com o dispositivo, só achei estranho a ausência de feedback na colisão do objeto carregado com os obstáculos do cenário, mas isso depende do que se quer testar no experimento, então não é nada de mais.
25	Gostei da tarefa, pois é algo que não se costuma utilizar em jogos
26	Interessante a interação entre visual e tátil para noções de espaço
29	Divertida
30	*Fiquei com o sentimento de que uma parte muito importante, senão a mais significativa da tarefa, diz respeito a sincronizar sua ação com a ação do seu parceiro. Pois é preciso corrigir os erros cometidos por você, e os erros cometidos pelo parceiro. * Acho que combinar o feedback visual com vibração seria interessante. * Se o objeto sendo movido não passasse através de outros obstáculos penso que seria interessante para forçar o movimento correto.
31	Achei muito legal, apenas senti uma dor no braço por ficar muito tempo na mesmo posição. Talvez tivesse um lugar para apoiar o braço resolveria esse problema.
32	Achei a tarefa legal mas muito repetitiva
33	Gostei
34	Dependendo da orientação do objeto, uma das esferas ficava escondida no lado "de trás" do objeto, impedindo o controlador daquela esfera de perceber o feedback visual, por exemplo.

	No mais, o experimento foi interessante e o retorno tátil facilitou bastante a percepção de quando eu me desprendi do objeto.
35	o retorno tátil é mais natural
36	Poderia ter um retorno visual ou tátil quando o objeto manipulado sair da "rota"
39	Achei entediante e muito desconfortável quando o motor vibrava.
40	Achei top
42	Achei bem interessante. O que poderia ter, é se a peça que movimentamos, nunca saísse de dentro do arame, mas quando ela tocasse no arame, aí sim vibrasse, alertando. Como também, quando a peço encostasse em um dos obstáculos.

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