

A passive stringed haptic system for immersive environments

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Abstract. We propose a passive haptic feedback system that can provide the user with grounded forces in a 3D manipulation space. A visual/haptic interaction is used to control forces returned by the system, which is composed of cables and a braking system. An experiment, consisting of two sessions of stickiness comparison tasks, is conducted to evaluate the device. The first session is done with the proposed haptic feedback, the second is purely visual, without haptic cues. We propose indicators for task performance and we measure the forces fed back by the device during the experiment. Results show that the device provides the users with actual forces that are consistent with simulated physical properties, and that it enhances user performance compared to the purely visual situation. Finally, the system is installed on a Responsive Workbench on which informal tests show that it provides the users with haptic sensations.

1 Introduction

A definition of passive haptic systems is systems that are not computer controlled. “Props” [1] are an example of passive haptic systems; they are rigid or deformable objects which provide feedback simply by their shape or texture, unlike active haptic devices that use computer controlled actuators.

Another possible definition was proposed by Swanson [2]: “*passive haptic displays are systems that are energetically passive, in the sense that they don't add kinetic energy to the system*” -unlike active systems- “*but are only capable of removing, storing, or redirecting kinetic energy*”. It is this definition that we will use in this work.

Props seem well suited to simulate reaction forces from solid objects such as a virtual cockpit, command buttons or walls, and might also be suitable for compliant objects (sponge, spring). However, it is difficult to change the simulated resistance or compliance of virtual objects since their haptic representation -the physical object- would have to be changed.

Some passive devices can adapt to changes in the virtual environment. The PTER (Passive Trajectory Enhancing Robot) was developed by Book et al. [3]

and makes use of electromagnetic brakes to constrain user movements. Such systems, that feed back forces to the user by constraining his movements (dissipating his kinetic energy), with computer controlled brakes or clutches are called *dissipative passive devices* by Swanson [2]. Cobots [4] are steerable systems that can constrain a user’s movements by reducing his degrees of freedom. These systems use computer driven actuators, and can be costly and complex to maintain.

Pseudo-haptic feedback was proposed by Lecuyer et al. [5], who defined pseudo-haptic systems as “systems providing haptic information generated, augmented or modified, by the influence of another sensory modality”. The experiment conducted by the authors showed the possibility of providing the user with haptic information by means of a passive input device combined with visual feedback. This passive technique makes no use of computer driven actuators and can be used to simulate different values of mechanical properties such as stiffness.

Haptic systems can provide grounded or non-grounded forces. Grounded systems can constrain user movements relative to the ground, such as the Cyber-Force [6], or the PhantomTM[7] and return grounded forces. They are opposed to non-grounded forces that are provided by portable systems, and can constrain the user’s movements relative to his own body.

The objective of this work is to propose a passive feedback technique that cumulates the advantages of totally passive devices (low cost, no computer driven actuators) and the advantage of computer driven passive devices (adaptation to changes in the virtual environment), that can simulate grounded forces in a 3D workspace.

The main question is how to constrain user movements in 3D space, depending on variable forces in the virtual environment, without an active, computer controlled device? The proposal of this work is to use a visual/haptic interaction, inspired by pseudo-haptic feedback. The visual/haptic interaction is meant to induce actions from the user to trigger reaction forces from a passive haptic device based on grounded cables and a braking system.

In Section 2, we describe the proposed passive haptic system and evaluate it in Section 3 in a virtual stickiness discrimination task. In Section 4 we discuss the results of the experiment on the basis of user performance and force measurements on the device.

2 Proposed passive haptic device

Pseudo-haptic feedback, proposed by Lecuyer et al. [5] makes use of an interaction between two sensory modalities, visual and haptic, without using a computer controlled actuator. The authors conducted an experiment using an isometric device (a Spaceball) allowing the user to move a virtual cube on a plane where a “sticky” zone is represented. When the cube is in the sticky zone, the displacement gain (object movement/user movement ratio) of the object is lowered. The reaction of the users was to press the device harder, causing higher reaction force from the device. The authors also conducted an experiment showing that pseudo-

haptic feedback can simulate stiffness of springs. For both cases, the device was put on a table and was not meant to move.

The system that we propose is based on a similar interaction between visual and haptic information. Our purpose is to provide the user with grounded forces that can occur in 3D manipulation space in an immersive environment. Thus, the device has to be mobile.

In the experiments on pseudo-haptic feedback, the displacement of the virtual object is rate-controlled, and the reaction of the device to user actions is inherent to its internal stiffness. In the case studied here, the device has to be mobile, and the user control on virtual objects is a position-control. For the rate-control case, control actions cause reaction forces from the isometric device. For the position-control case, there are no such reaction forces. An additional action to the position-control movements of the user is required in order to yield reaction forces from the system. We propose that this additional action of the user be a pressure on the device.

The principle of the system is (see also Figure 3): The user can move a virtual object in 3D space by moving the device. The device contains a tracker for movement acquisition, a force sensor ¹ and a braking device (see Figure 1). Strings go through the braking element, and when the user presses it, friction forces constrain his movements. When there are no virtual constraints on the object, the user can freely move it by moving his hand (see Figure 3). When the object is under a constraint, the displacement gain (object movement/user movement ratio) is lowered and the object visually moves slowly. In this situation, the user has to press on the device to raise the displacement ratio (according to his pressure measured by the sensor). Consequently, the pressure that the user exerts on the system constrains his translational movements on wires which are attached to the ground. In that situation, he is likely to feel actual resistance forces while he moves in the constrained area, see Figure 3.

In the system that we propose, visual feedback induces the user to press the device depending on visual feedback, and the system returns forces in reaction. We want the user to press on a brake that constraints his own movements. A real life situation where we create ourselves the constraints on our own movements is when we are riding a bicycle: when one presses the brake handles, he actually feels deceleration forces, and is able to modulate the pressure he exerts to brake properly. A one dimensional version of the braking system is shown on Figure 1) and extended to 2D and 3D (Figure 2).

This system is based on a visual/haptic interaction: when the object slows, the subject presses the device. Our concern is to see if this passive system actually feeds back forces. In the next Section we describe an experiment meant to investigate this question.

¹ (FlexiforceTMELFTM system, Sensor B101-L [8])

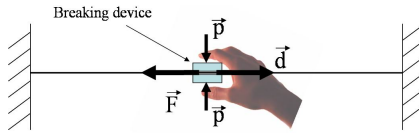


Fig. 1. 1D braking solution. When the user applies a pressure p on the braking system, a friction force F occurs during his displacement d . Since the string is fixed to the ground, the friction forces are grounded.

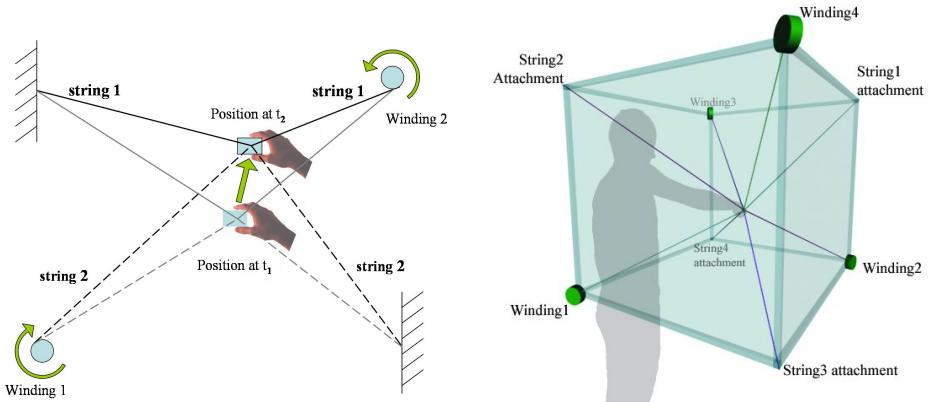


Fig. 2. **Left:** 2D solution, one end of each string is fixed to the ground, the other is fixed to a winding so the length of the string can vary. **Right:** Schematic view of the passive haptic system (3D version). 4 strings are attached to 4 corners of a cubic structure, each string can wind and unwind at the opposite corner

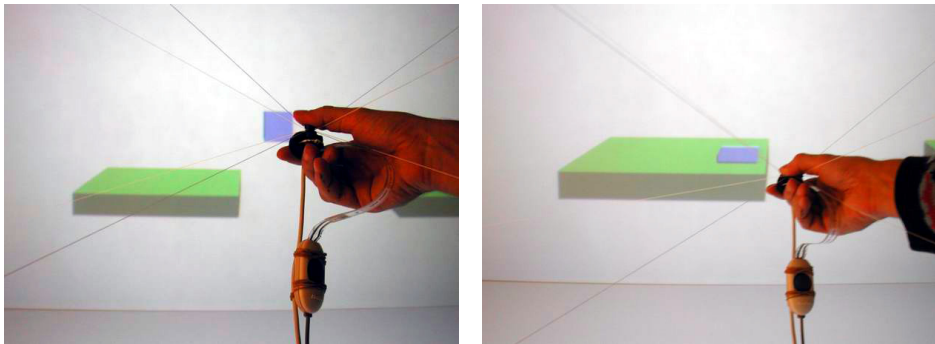


Fig. 3. **Left: Unconstrained displacement.** When the virtual object (small cube) is under no constraint the user doesn't have to press the braking device to move it, and his movements are free. **Right: Constrained displacement.** In order to move the virtual object in the sticky area, the user has to press the device. Consequently, his movements along the *strings* are constrained.

3 System Evaluation

3.1 Method

To evaluate the system, we had a group of subjects perform a stickiness discrimination task. The users had to compare the virtual stickiness of two areas placed on a virtual plane. For this experiment, the simulation was displayed on a 25 inch CRT monitor, and runs on a Sgi Onyx2 computer. Users controlled a virtual cube which could move on the plane and inside the sticky areas. The movements of the cube were visually constrained inside the sticky areas, according to each area's simulated stickiness. The experiment consisted of 2 sessions, one session using the passive haptic feedback (HAPTIC session), and a session with haptic feedback disabled (VISUAL session). The stickiness of the reference area was constant. For the comparison area it varied from -30%, -20%, -10%, 10%, 20% and 30% of the reference stickiness, yielding 6 comparison pairs. Each comparison pair was presented 3 times in a random order, yielding 18 comparison tests for each session. For each test the subject was asked to choose which of the two areas seemed the stickier. 18 subjects participated in the experiment, 16 men and 2 women, aged from 20 to 29. 2 were left handed, 16 right handed.

3.2 Gathered data and results

Indicators used to describe user performance were:

Score: The overall score is the number of correct answers given by all subjects, considering that the reference for each answer is the relation between the reference and comparison stickiness. Overall score is 69.7% for visual session and 77.4% for haptic session.

Just Noticeable Difference : We followed the usual method described in [9] to compute the Just Noticeable Difference (JND), which is the smallest increment in stimulus (here, comparison stickiness) that is perceived by the user. The PSE is the value of the comparison stimulus that is perceived to be equal to the reference one. JND found is 25.8% for VISUAL session and 22.8% for HAPTIC session. Respective PSE values are 1.13 and 1.23 (virtual stickiness values), corresponding to overestimations of 0.4% and 9% of the reference value (1.125).

Applied force : The forces applied on the system were gathered to investigate if actual forces felt by the user are consistent with the simulated stickiness.

4 Discussion

The main issue in this work was to investigate if the proposed system could return forces that are consistent with the virtual forces we intend to simulate. The data for average *applied forces* on the *comparison* area show that the stickier the comparison area, the harder users press the device. Furthermore, this relation between the force we intend to simulate and the average force returned by the system is close to linear ($R^2 = 0.9624$). Secondly, the system increases performance: this result tends to show that the system brings additional information

compared to the visual session. Results for *score* and *applied forces* strengthen the idea that this additional information is not an illusion, but indeed actual forces, consistent with the simulated property.

We conclude that the system can be used to feed back haptic information: for example it can be suitable to simulate variable electromagnetic force fields in a scientific visualisation application.

5 Conclusion

We have proposed a passive haptic display that doesn't make use of computer driven actuators and provides the user with grounded forces in 3D workspace. Results show better resolution (JND) in perception of simulated forces when using the system, compared to a situation where no haptic information is available. Secondly, the forces applied by the users to the device are consistent with the simulated property: the stickier a presented virtual area is, the harder the user presses the device and constrains his movements in that area.

The system was installed on a Responsive Workbench, showing its adaptability. On the basis of informal tests on the workbench, users reported having haptic sensations such as stickiness or viscosity. This experiment involved comparison between two virtual properties and further work will evaluate the ability of the system to simulate properties that could be compared to real physical properties, for example, present the user with a real viscous object and compare it with a virtual one, simulated with this passive feedback.

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