Defense Technical Information Center Compilation Part Notice

ADP010787

TITLE: Simulating Haptic Information with Haptic Illusions in Virtual Environments

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: What is Essential for Virtual Reality Systems to Meet Human Performance Goals? [les Caracteristiques essentielles des systemes VR pour atteindre les objectifs militaires en matiere de performances humaines]

To order the complete compilation report, use: ADA390882

The following component part numbers comprise the compilation report:
ADP010779 thru ADP010796

UNCLASSIFIED

Simulating Haptic Information with Haptic Illusions in Virtual Environments

Anatole Lécuyer[1]
Aerospatiale Matra CCR
12 rue Pasteur, 92152
Suresnes, France

Sabine Coquillart
INRIA Rocquencourt
Domaine de Voluceau, 78153
Le Chesnay Cedex, France

Philippe Coiffet
LRP – CNRS
10-12 avenue de l'Europe, 78140
Vélizy Villacoublay, France

Abstract

This paper presents a set of experiments in which a human user feels haptic sensations. These sensations are in fact haptic illusions, generated by a visual effect. Then, these haptic illusions are described and analysed.

These haptic illusions were generated by the use of a pseudo-haptic feedback system. It is a system combining an isometric input device and visual feedback. The experimental apparatus did not use any force feedback interface.

The paper addresses the role of action in the perception loop — subjects felt a reactive force corresponding to their own sensory-motor command. In addition, subjects had to "participate" in the illusion process by choosing the cognitive strategy, which led to the illusion.

In the future, the use of the concept of illusion might improve or simplify VR simulations and pave the way to a better understanding of human perception.

1. Introduction

The challenge of VR technology applied to aeronautical virtual prototyping is the backdrop to the study. Nowadays, virtual prototype designers should take into consideration the assembly and the support constraints as early as possible in the development process. Indeed, the operator (or the designer) should have the possibility to feel and interact more physically with the mock up. It is therefore essential to allow haptic feedback in virtual assembly and support operation simulations.

Haptic feedback devices will soon provide new and indispensable possibilities [4]. But today these interfaces remain expensive and complex. Thus, there is a need for other replacement solutions.

In the absence of a haptic interface, a previous paper [10] studied the possibility to simulate force cues with an input device within a virtual environment (VE). This device is the 2003C model of the Logitech Spaceball™ [3], which is an isometric device — "isometric" meaning that the Spaceball™ is nearly static and remains in place while a pressure is being exerted upon it. The force feedback was simulated by using the mechanical characteristics of the passive device: its internal stiffness and its thrust — and by combining them with an appropriate visual feedback. The result of this visio-haptic feedback was called "pseudo-haptic" feedback [10]. The pseudo-haptic feedback was established qualitatively and quantitatively following different psychophysical experiments.

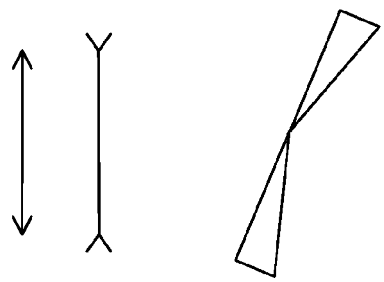
The simulation of force feedback by pseudo-haptic feedback can be considered as a phenomenon of haptic illusion. An illusion is a non-veridical perception. It is a mistake made by our brain and not by our senses. The effect of illusion can be generated by means of art, artefact or special effects. This effect can be perceived but is not real.

The objective of the study is to analyse some haptic illusions involved in the pseudo-haptic feedback, in order to introduce the concept of illusion in the design of virtual environments.

After addressing previous work on haptic illusion, this paper describes two different experiments, which were carried out to demonstrate the potential of pseudo-haptic feedback. Then the paper studies the haptic illusions, which are generated by these experiments. Finally, it assesses the perceptual mechanisms involved in the process as well as their potential.

2. Previous Work

Some well-known optical illusions such as the Müller-Lyer illusion (see Figure 1a) or the Zollner illusion are extensively described in scientific works [8]. Many examples of famous illusions can be found on the web [1]. And there are even companies whose business is devoted to developing educational and fun products relating to visual illusions [2].



a **b**

Figure 1: Müller-Lyer Illusion : the left segment looks smaller than the right one [**a**]; Bourdon Illusion : the left border looks slightly bent [**b**]

But illusions may occur on the other sensorial modes. An auditory illusion [2], composed by Roger Shepard in

[1] For contact with authors: anatole.lecuyer@aeromatra.com, sabine.coquillart@inria.fr, and philippe.coiffet@robot.uvsq.fr

Paper presented at the RTO HFM Workshop on "What Is Essential for Virtual Reality Systems to Meet Military Human Performance Goals?", held in The Hague, The Netherlands, 13-15 April 2000, and published in RTO MP-058.

1964, is a transposition of the famous endless stairs drawn by the Dutch graphist M.C. Escher on the auditory mode. Shepard played on a keyboard an ascending or descending chromatic or diatonic scale using four parallel octaves simultaneously. The tones were perceived as continuously increasing or decreasing in pitch, however after travelling over an octave, they were the same in pitch as when first started.

The existence of haptic illusions can be revealed by simple experiments. For example, considering three jars of water; from left to right, the temperature varies from warm, tepid to cold. When the hands are first dipped into the outer jars the water is perceived as warm on the left hand-side and as cold on the right hand-side. Then, when dipping both hands into the middle container, one perceives again two different temperatures, this time however, in reversed order cold on the left and warm on the right, though the water is neither warm nor cold but tepid.

The Thaler haptic illusion can also be simulated very simply. One can observe that the temperature of an object influences the haptic perception of its weight: a cold coin seems heavier than a coin of the same size but warmer [12]. Thanks, probably, to the fact that perception of coldness and that of heaviness share common neurones.

Another example described in [5], is the haptic equivalent of the Bourdon's visual illusion (see Figure 1b). Day used a 3D volumetric model of the Bourdon Figure. When a person explores the two opposite surfaces of the model with his/her thumb and forefinger, he/she feels the upper and straight surface as being slightly bent. On average, people felt a bend of 3.8 degrees *visually* and a bend of 3.5 degrees *haptically*.

Researchers do not always agree on what causes illusions, and many illusions remain "unsolved". Ellis and Lederman focused more precisely on the origin of illusion as located on the visual mode or the haptic one. They studied the famous size-weight illusion [7] and the material-weight illusion [6] — the size-weight illusion occurs when a large radius ball seems heavier than a ball of the same weight but with a smaller radius. The material-weight illusion is the influence of the texture of an object on the perception of its weight. Ellis and Lederman established these two illusions as a primarily haptic phenomenon, despite the size-weight illusion was traditionally considered as a case of vision influencing haptic processing.

Some works deal with consequences of illusions on perception or on the performances of our motor system. Volker studied the influence of visual illusions on grasping [15]. Different subjects were presented fins on a monitor screen being directed either outwards or inwards such as in the Müller-Lyer illusion (Figure 1a). During the grasping task, subjects were told to grasp the fin, and the maximal aperture between thumb and index finger was measured. During the perception task, subjects were told to adjust the length of a comparison bar on the screen to match the length of the fin. Volker showed that there were strong effects of the Müller-Lyer illusion on grasping as well as on visual perception, indicating that the motor system is also receptive to visual illusions.

In a VR simulation, Hogan studied haptic illusions occurring during the exploration of virtual objects and their implications on the perceptual representation of these objects [9]. He used a force feedback arm constrained to move on the 2D horizontal plane. Subjects grasped the handle of the arm and were asked to evaluate the length and stiffness of virtual rectangle objects. The handle was grasped and moved around the virtual rectangles. During the task, the subject had to choose the longer (or the stiffer) stimulus of two stimuli. One stimulus was evaluated on the X-axis of the horizontal plane, while the other was evaluated on the Y-axis (i.e. each stimulus depended on a side of the rectangle). Results show that for the same stimulus on the X- and Y-axis, a difference of perception occurs according to the distance of the handle from the shoulder (as if the vertical-horizontal visual illusion was projected in the haptic mode, on the horizontal plane). Hogan stated that these haptic illusions show that the internal model of haptic perception is not metrically consistent. This property should significantly modify and simplify the performance constraints in forces computation.

It seems that very few VR papers explored the possibility to use illusions directly in the conception of a VE.

This paper presents and analyses haptic illusions, which were showed by two VR experiments. The next part describes the two experiments and their results.

3. Pseudo-Haptic Experiments

The concept of pseudo-haptic feedback relies on coupling the visual feedback with the internal resistance of the isometric device, which naturally reacts to the force applied by the user. The overall system returns a force information called pseudo-haptic feedback.

For example, let us assume that an operator manipulates a virtual pipe in a virtual environment within the frame of an insertion task evaluation. The pipe is displayed on the monitor, and moved by means of the Spaceball™. It is to be inserted into a virtual duct. As the pipe penetrates the duct, its speed is slowed down. The user instinctively increases his pressure on the ball, which results in the feeding back of an increasing reaction force by the static device. This combination of visual effect and growing reactive force is then expected to generate cues of friction.

In order to study the pseudo-haptic feedback concept, different experiments were conducted. Two of them are described in the following paragraphs.

3.1 The "Swamp" Experiment

Description

The swamp is a quantitative evaluation of the pseudo-haptic feedback. 18 people took part in this experiment. Each subject was told to manipulate a virtual cube in a

3D virtual environment (see Figure 2). The cube was manipulated in 2D on the horizontal plane with either a classical 2D mouse or with the Spaceball™.
As the cube moves over a grey area, its speed is accelerated or slowed down. At this very moment, the subjects were asked to describe and compare their sensations when using the 2D mouse or the Spaceball™.

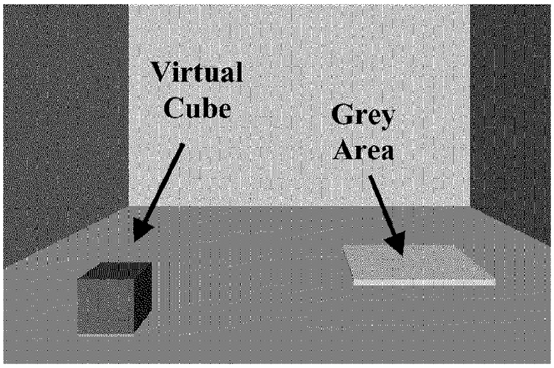


Figure 2: The Swamp experiment display

Results
A quantitative comparison between an isometric device and an isotonic device must be taken cautiously since these interfaces are not used in the same way. But the swamp example *did* display some global tendencies.
A great majority of people logically found that the use of the two interfaces were very different. The need for a learning phase with the Spaceball™ generally disturbed subjects when starting their manipulation.
The subjects systematically perceived the following phenomena: *friction*, *gravity* or *viscosity*, when the cube was slowed down with both devices. Conversely, they perceived a sense of *gliding* or *lightness* when the cube was accelerated.

Great majorities of people found that the sensations they felt were different while using the Spaceball™ or the 2D mouse. Nearly all of the subjects chose the Spaceball™ as the interface with which the "forces" were more perceptible. This sensation was less obvious when the cube was accelerated — which is probably due to the fact that the reactive force from the static device is more efficient during a compression phase.
The quantitative indications provided by the swamp experiment were very useful to show us the potential of this concept, but they didn't measure the characteristics of the generated feedback. It was necessary to evaluate more qualitatively the pseudo-haptic information: to do so a psychophysical experiment has been conducted

3.2 Discrimination between a Virtual Spring and a Real One

Description
The psychophysical task, which was chosen, is manual compliance discrimination between a virtual spring and a real one (see Figure 3). The real spring is embedded inside a piston, like a "trumpet piston" (see Figure 3).

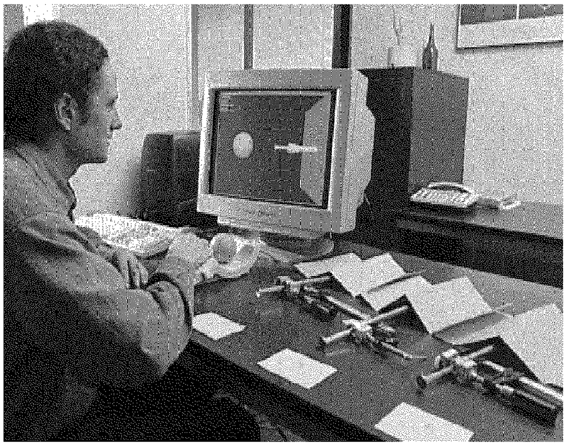


Figure 3: Psychophysical experiment — Manual discrimination between a virtual spring and a real one

The virtual spring is a combination of the input device and the visual feedback (see Figure 4). A hand-made apparatus was fixed on the Spaceball™ to obtain the same catching in the virtual environment and in the real one. The virtual spring is visually displayed on the computer screen. It is made to appear as similar as possible to the real piston. The force applied on the ball by the user controls the visual displacement of the virtual spring. When pressing the virtual spring, the user's thumb barely moves, since the Spaceball™ is an isometric — hence static — device.

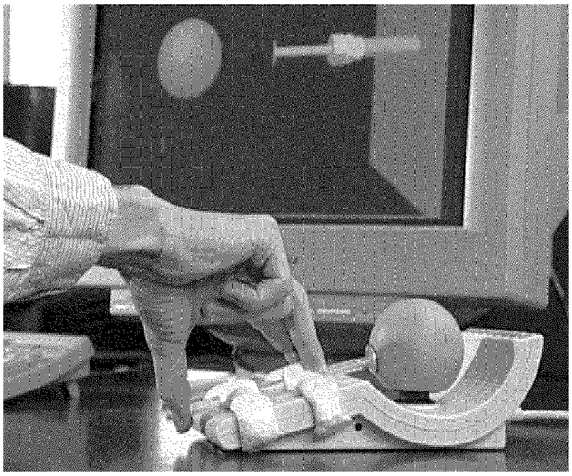


Figure 4: Virtual spring set-up

27 people took part in this experiment. There were 972 trials per subject. During each trial, each subject was asked to test a real spring and a virtual one and to select the one, which seems to him to be the stiffer. There were three possible real springs with three different degrees of stiffness. And each real spring was compared with 12 different virtual springs.

Theoretically, a "stiffer" virtual spring corresponds to a case when the force — which is required to move the visual display of the piston on the screen along a certain distance — is bigger than the one which is required to move the real spring along the same distance.
(For a complete description of this experiment see [10].)

Results
The large volume of collected data made it possible to calculate a psychophysical parameter called the Just Noticeable Difference (JND). The resulting average JND for the manual compliance discrimination between a virtual spring and a real one is equal to 13.4%. It is consistent with previous studies on compliance discrimination between two springs simulated within a single environment [13].

This consistency shows quantitatively that a system, which combines visual feedback and an isometric device, can provide force cues, which are comparable with real ones.

4. Illusions Observed

The whole concept of pseudo-haptic feedback relies on a phenomenon of haptic illusion. In the course of the two experiments, the haptic perception is mistaken by a visual effect. The visual feedback generates a new haptic interpretation of a virtual scene, thus a haptic illusion.

This assumption is confirmed by the simple fact that if one closes one's eyes during one of these two experiments, the experimental task becomes impossible, and the haptic sensations vanish.

During the first experiment, the perception of friction when crossing the grey area in the virtual environment is linked to the visual variation of the speed of the cube. The whole set-up generates a haptic illusion of several haptic attributes of the cube — heaviness, lightness — or of the grey area — rugosity, viscosity, and friction.

In the course of the second experiment, without the visual displacement the haptic perception of the virtual spring remains the same, i.e. the Spaceball™ internal stiffness. The pseudo-haptic set-up generates the haptic illusion that different springs are being manipulated. It becomes possible to perceive different stiffness with the same Spaceball™.

One more illusion phenomenon is revealed in the course of the second experiment by a question asked to the last ten subjects. These people were told to draw a straight line corresponding to the maximum displacement of the thumb when pressing a virtual spring. The result indicates an average overestimation of 5 times their actual displacement (see Figure 5). It means that they completely assimilated the visual displacement on the computer screen to their own thumb motion. In other terms, it implies an illusion of their proprioceptive sense.

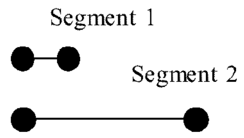


Figure 5: Illusion of the Proprioceptive Sense. Segment 1 — real maximum displacement of the user's thumb; Segment 2 — estimated displacement of the user's thumb

5. Discussion

The pseudo-haptic feedback is not an illusion of force feedback. There is actually a force feedback during both experiments when actuating the Spaceball™:

First, because in all manipulation tasks there is a force feedback reaching the brain — in terms of pain or fatigue for example. Broadly speaking, even when one simply holds something in one's hand or wants to grasp an object, the motion command sent from one's brain activates the muscles of the arm, and makes the one feel efforts or tensions in his/her muscles or his/her tendons. These efforts being sent back to the brain via the afferent neurone network.
The manipulation of the virtual cube with the 2D mouse in the first experiment could then be considered as a case of pseudo-haptic feedback with an isotonic device. The speed of the cube was decreased when passing over the grey area, then the user had to increase his arm motion, spend more energy on this gesture, and this may lead to the friction effect.
In addition to the afferent signals coming from the different mechanoreceptors, some efferent mechanisms play a role in human kinaesthesia. Such as the "innervating sensation" [14], which occurs when one overestimates the weight of an object when tired. It is a distortion of force perception, which is due to our own command system. Our will to achieve an action generally makes us feel the anticipated result of this action before it actually happens. And this introduces the role of action in the perception loop of illusion.

Then, a force feedback from the static device is also present. It is not an "active" force feedback — i.e. a computed force feedback — different from other force feedback systems such as the PHANToM™ [11] of SensAble Technologies. The current force feedback is provided by the reactive force coming from the Spaceball™. And since the Spaceball™ is nearly static, it means that the reactive force is nearly equal to the force applied by the user on the ball. It is a characteristic of the pseudo-haptic feedback with an isometric device: the force feedback is always equal to the force command. This is illustrated on Figure 7.

Figure 6 and Figure 7 show the difference of information flux in a pseudo-haptic system and a haptic one. In the case of a classical haptic feedback system such as the PHANToM™ (see Figure 6), the user transmits a motion which is sensed by the optical encoders of the PHANToM™. The force feedback device sends back to him the computed virtual force, which is a function of the interference between the probe and the virtual elements of the virtual environment. The visual feedback doesn't play a major role in the haptic perception process.

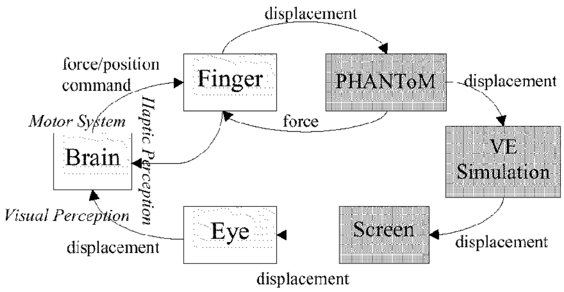


Figure 6: Haptic feedback system

In the pseudo-haptic case (see Figure 6), the user transmits his force command to the simulation by means of the force sensors of the Spaceball™. At each simulation step, the force fed back is constantly equal to the opposite of the force applied. The user receives exactly the same force as the one he has just applied. The haptic profile of the force vs. displacement is given by the Spaceball™ internal stiffness. This profile corresponds to the one of a constraint gauge; this profile is not linear. The final haptic perception is achieved by combining the force information and the visual impact of this information in the VE. It means that the Spaceball™ internal stiffness is somehow "mapped" on a visual event. In reverse, the visual effect gives sense to the force information.

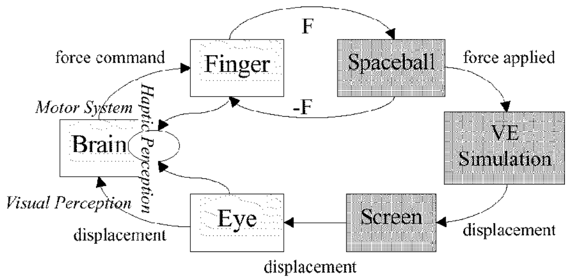


Figure 7: Pseudo-haptic feedback system

An obvious consequence of this characteristic being that the pseudo-haptic experiments, which were described, cannot work without visual feedback.

The pseudo-haptic feedback process system implies that the user receives his/her own force command in return. Indeed, the whole pseudo-haptic feedback depends on an action as well as a participation of the user during simulation: in the course of the swamp experiment, the friction sensation occurs if the user increases his pressure on the ball when the cube motion is slowed down. This probably happens if he/she decides to keep the virtual cube at fast motion, which is a cognitive strategy relying on many factors affecting the subject (passivity, availability, stress, etc.). This would imply that pseudo-haptic feedback and haptic illusion could also depend on cultural or contextual reactions of the subject.

In the course of the compliance discrimination task, the subject had to recompose the stiffness of a virtual spring with information coming from different modalities. In addition, there was a conflict concerning the spring displacement between the proprioceptive information and the visual one.

Since they were able to compare the final model of the virtual spring with a real one, the result of the experiment shows that subjects succeeded in recombining sensory information. It implies that they made the choice to use the visual displacement rather than the proprioceptive displacement. This choice is the result of an unconscious participation of the user in pseudo-haptic simulation, and is the reason why the illusion appeared.

For the time being it is difficult to know if this choice is:

- an example of a sensory substitution or sensory dominance, which corresponds to the following expression: *Vision dominates Touch ⇒ I use the visual displacement to evaluate virtual springs,*
- or, an example of a choice between different cognitive strategies. I must choose among all possibilities one that can help me to perform my discrimination task, and eliminate other strategies. This rather corresponds to the second expression: *I must evaluate a virtual spring ⇒ I choose the visual displacement (and not the proprioceptive one) which makes it possible.*

In other terms, is the proprioceptive illusion due to a characteristic (or a limit) of human perception system (= "peripheral" view); or is it due to a decision process made in a strategic situation (= "central" view).

This alternative has a direct impact on the conception of VE's which are to be based on pseudo-haptic feedback or sensory illusions. There is indeed, a need for further investigation concerning the generation of illusions.

6. Conclusion

The paper has presented VR simulations in which force cues or haptic behaviours are simulated with a pseudo-haptic feedback. This pseudo-haptic feedback comes along with phenomena of haptic illusions. It is not an illusion of force feedback, but rather an illusion of using a force-feedback device.

The analysis of a pseudo-haptic feedback system shows the role of the sensory motor command in the perception loop, and also points to the unconscious participation of the user in the illusion, which is linked, to his/her cognitive strategy during the experimental task.

Designers of virtual environments, who usually try to recreate human stimuli in an anthropomorphic manner, could envisage a wider use of this concept of illusion.
The method, should it exist, implies to revise the simulation process and the use of human-computer interfaces. The designer has to think in terms of sensory information feedback. He/she has to decompose the sensory information into its different sensory modalities, and to reshape it into a new sensory distribution. To do so, he/she can make full use of all the possibilities that are known in the field of sensory illusions and sensory substitutions.
It is necessary to facilitate the repositioning of the user perception to an "implicit" solution. It means that this implicit sensory alternative must be explicit enough to be found quickly by the user.
For example, in the case of the second experiment, the information needed was the displacement of the virtual spring, and its implicit alternative was the visual displacement.

Future work must develop and evaluate more cases in which sensory illusions are used for VE interactions. The overall objective is to propose an empirical method to incorporate illusions in the conception of VE's.

Acknowledgements
The authors would like to thank Mr P.R. Persiaux, Mr. D. Tonnesen and Mrs. M.J. Paškauskaitė for their valuable remarks.

References
[1] http://www-psy.ucsd.edu/~sanstis/SASlides.html
[2] http://www.illusionworks.com
[3] http://www.spacetec.com
[4] G. Burdea. *Force and Touch Feedback for Virtual Reality*. John Wiley and Son, US, 1996
[5] R.H. Day. The Bourdon Illusion in haptic space. *Perception and Psychophysics*, 47, 400-404, 1990
[6] R.R. Ellis and S. J. Lederman. Modality, Weight and Grip Force Effects in the Material-Weight Illusion. In *Proc. of the Canadian Society for Brain; Behavior and Cognitive Science Annual Meeting*, 1995
[7] R.R. Ellis and S. J. Lederman. The Role of Haptic versus Visual Volume Cues in the Size-Weight Illusion. *Perception and Psychophysics*, 53(3): 315-324, 1993
[8] E.B. Goldstein. *Sensation and Perception*. Brooks/Cole, US, 1999
[9] N. Hogan, B.A. Kay, E.D. Fasse, and F.A. Mussa-Ivaldi. Haptic Illusions : Experiments on Human Manipulation and Perception of "Virtual Objects". *Cold Spring Harbor Symposia on Quantitative Biology*, 55:925:931, 1990
[10] A. Lécuyer, S. Coquillart, A. Kheddar, P. Richard, and P. Coiffet. Pseudo-Haptic Feedback : Can Isometric Input Devices Simulate Force Feedback? In *Proc. of IEEE International Conference on Virtual Reality*, 2000
[11] T.H. Massie, J.K. Salisbury. The PHANTOM Haptic Interface : A Device for Probing Virtual Objects. In *Proc. of ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems*, 1994
[12] Sherrick and Cholewiak. A Finite Element Formulation for Nonlinear Incompressible Elastic and Inelastic Analysis. *Computers and Structures*, 26(1/2):357-409.
[13] H.Z. Tan, N.I. Durlach, G.L. Beauregard, and M.A. Srinivasan. Manual Discrimination of Compliance Using Active Pinch Grasp: the Roles of Force and Work Cues. *Perception and Psychophysics*. 57(4):495-510, 1995
[14] C. Tzafestas. *Synthèse de retour kinesthésique et perception haptique lors de tâches de manipulation*. Ph.D. Thesis, Université de Paris 6, Jul. 1998
[15] F. Volker, M. Fahle, K.R. Gegenfurtner, and H.H. Bülthoff. Grasping visual illusions: No difference between perception and action? *In Proc. of ARVO Meeting*, 1999