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# PRESENCE: the sense of believability of inaccessible worlds

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**Abstract**

With the development of new instruments as telecommunication, teleoperation, computer representation tools, human beings are commonly in situation to perceive and act on spaces that are more and more distant or different from our physical world. These new tools raise nowadays the question of Presence of these distant spaces with a growing intensity. This question crosses disciplines as different as computer arts or nanosciences. Through two experimental situations in each of these fields, (1) the playing of a musical virtual instrument and (2) the manipulation of nano-objects, the paper analyses the minimal conditions that the computer models and the human–computer interactions have to satisfy to trigger the sense of presence of distant inaccessible objects, whatever they are. After examining the evolution of instrumental tools, machines and concepts from real means to televirtual ones via the teleoperation and telecommunication chains and via experiments for the investigated fields, the paper shows that the primary condition able to generate ab initio the sense of presence, should be the instillation of a minimal physical coherence in the representation of distant worlds, and the introduction of the "evoked matter" concept as a central paradigm for the Presence issue.


*Keywords:* Virtual reality; Haptic interaction; Physically based multisensory rendering; Nanomanipulation; Computer arts

## 1. Introduction

Historically, the idea of a virtual world emerged from the evolution of our representation and manipulation tools. This concept reflects the convergence of two research fields: on one hand, the science and technology of representation (simulation, synthesis); and on the other, the science of observation and instrumental manipulation (physics, biology, etc.).

Concerning the first, the progress of synthesis and simulation techniques has given birth to synthetic worlds that can be seen, heard, touched, and manipulated, as the real world, revealing the difficulty of rendering them as present as real objects [1,2]. Synthetic worlds are commonly used today in telecommunication, as a generic means of representation for humans and for communication between them. The finest part of this evolution is the Virtual Reality (VR) concept, more recently enhanced by the concepts of Augmented Reality (AR) and Mixed Reality (MR).

Concerning the second, during this century, a striking epistemological break occurred in the designing of new instruments as well as of new theories. On one hand, we build instruments to explore and manipulate, more and more deeply, worlds that are not accessible to our senses and our common knowledge. On the other hand, our contemporary theories seem to be more and more foreign to the common human senses. For example, it is currently assumed that classical physics is closer to human understanding than quantum mechanics. The concepts of telepresence and telesymbiosis, widely used in Virtual Environments, appeared first in teleoperation [3] by trying to bring such inaccessible worlds in (i.e. *to be present in*) our real world, or conversely, to carry human beings in (i.e. *to be present in*) the distant world.

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Teleoperation platforms for action, perception, and multisensory information processing have been developed [4,5] to allow us to interact with more and more *distant* objects, inaccessible to our common senses and cognition.

Three complementary questions summarize the problem addressed under the concept of Presence: ‘‘Why do distant, synthetic, cyber, inaccessible worlds seem insufficiently present or real for us? Why, and How can we render them more ‘‘present’’ for our perceptions, actions, and cognition?’’

In order to allow reliable concepts and techniques to overcome these problems, we address these questions from the very different points of view of Computer Sciences, particularly Computer Arts and Physics, particularly nanosciences and nanotechnologies.

## 2. Presence in arts and nanosciences

### 2.1. Why Presence in Computer arts?

In Computer arts, as a result of the extensive developments in computer sound synthesis and computer animation of the last 20 years, we understand today that a complete physical reproduction of reality by means of Computers is unreachable and in addition unsatisfying. Conversely, the purely synthetic imaginary sounds and motions have equally fallen in a similar limit of their acceptability by human perception, cognition and aesthetic judgment. As a haunting underlying, the problem of Presence remains still unsolved: Why do these synthetic sensorial phenomena, despite their degree of realism or their ability to explore new artistic fields, continue to sound more artificial than previous ones? For example, what are the minimal modeling and sensory-motor conditions able to offer us for truly play a virtual violin, with musical expressiveness? It is obvious that the answer is not in the realistic reproduction of the morphological properties of the objects themselves, violin and bow. Thus, we assume that a key challenge is covered in the sensory-motor rendering of the instrumental relationship between instrumentalist and the instrument more than in the rendering of the objects themselves.

### 2.2. Why Presence in physics and nanosciences?

In experimental sciences, nanosciences operate a paradigm shift in the instrumentation field. The Atomic Force Microscope (AFM) observes the nanoworld through the forces, which circulate between a nanotip and a nano-object. It is not only a tool to observe but a tool that acts on the world, where the observation is

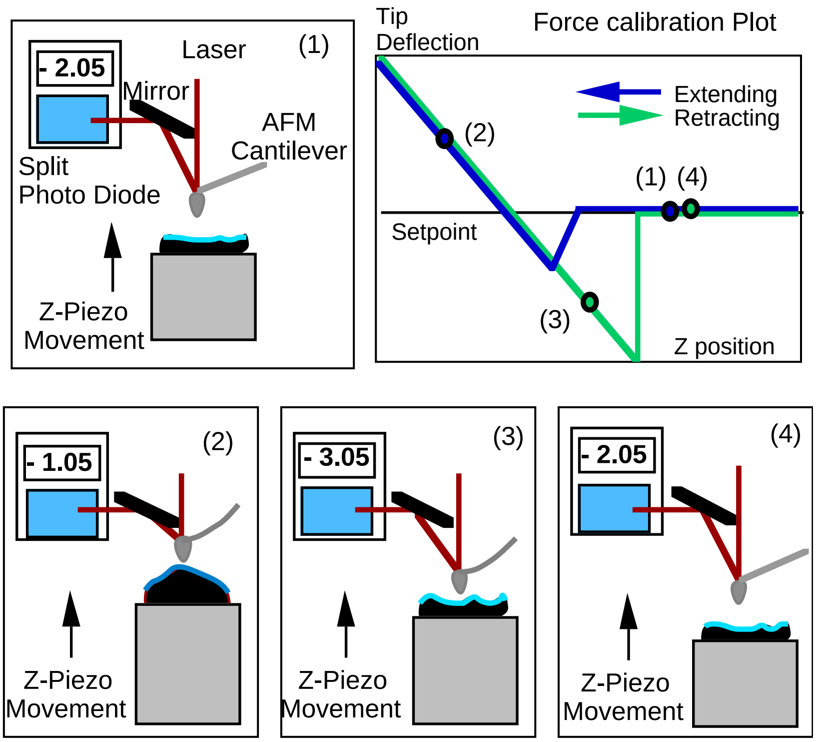


Fig. 1. Dynamic of the hysteresis tip–surface interaction.

intimately correlated to the action. This leads to two contradictory tendencies: the investigation could destroy materials and instruments when the action is not well controlled, and conversely, we have a new tool to build nano-objects, molecules by molecules, atoms by atoms. The accurate on-line control of the manipulation by experimentalist becomes, de facto, a new crucial challenge that always raises the same questions related to the presence issue: What are the minimal sensory-motor and modeling conditions to observe nano-objects and to build them by hand? Why and how can we render sensorial such inaccessible physical laws?

One of the basic phenomena frequent in nano-observation, is the approach–retract interaction. When the tip comes down to the surface (Fig. 1.1), it moves freely until it arrives at a certain distance $D1$ from the surface. After this threshold, the tip and the surface attract themselves with a certain force $F1$, which keeps them stuck (Fig 1.2). To de-stick them, we have to pull the tip with another force $F2$ (Fig 1.3), the separation occurring at another threshold $D2$ (Fig 1.4).

This tip–surface interaction produces a complex hysteresis phenomenon that cannot be revealed only by the representation of the interacting objects. The force and the distance $(F1, D1)$ when the AFM tip approaches the surface differ from those corresponding to the tip–surface separation $(F2, D2)$. It is then extremely useful to bring to the experimentalist a clear, immediate, non-deliberative representation of this hysteresis phenomenon *during the manipulation*.

This situation is similar to that of a violin–bow interaction: we have to render to the instrumentalist, a phenomenon, and not the objects themselves, that is their interaction.

In conclusion, these two apparently extreme examples address the core question of the mystery of Presence, that is, in fact, the question of absence. But the absence of what?

## 3. Is presence a new problem?

The distinction of what is *real* and what is *non-real* is an usual and long lasting question of philosophy as well as of the physics. During ages, several concepts have been confronted [6]:

(a) from radical idealism, sometimes called "critical idealism", defended by the neo-kantien philosophers for whom the reality—the *noumenon*—does not exist in itself, i.e. independently of our representations, having access only to the *phenomenon*,
(b) to ontological realism which assumes that science is able to lead to an exact and exhaustive knowledge of the ultimate reality,
(c) via Kant's transcendental idealism, which assumes that the reality in itself—the *noumenon*—may exist, even if it is essentially unknowable, and accessible only through the phenomenon,
(d) or via objective realism, that is probably the main position of experimental sciences nowadays and which assumes that the contingent properties of the universe are not only appearances but intrinsic realities that exist independently of the observers,
(e) and theory of Veiled Reality of Bernard d'Espagnat [6] for whom reality remains intrinsically unknowable in details but the knowledge developed by physics as description of the phenomena, enlightens the structure of a underlying reality.

The problem of Presence addresses not only the philosophical level but also the psycho-cognitive levels. Remembering that psychology was in the past a part of philosophy and that it joined the fields of experimental sciences recently, with psychologists as P. Piaget, we can answer that the problem of Presence, considered from these points of view, is not a novel question. What has occured recently, that could enlighten its re-emergence with its new force?

We assume that this occurs from a radical change in our instrumental tools that allows to shift this question from an abstract and conceptual level to an experimental level. To further clarify the new aspects of the presence question, we have to ask the historical evolution of our instrumental tools, from teleoperation to synthetic worlds.

## 4. From teleoperation to synthetic worlds

An explicit problem of Presence occurs whenever human beings manipulate real objects, directly or indirectly through mechanical instruments. The lack of Presence was felt from the moment when the communication between human beings, or between them and the physical universe became deeply mediated. We distinguish two successive steps: the apparition of electrical communication in the teleoperation process and the production of real sensorial data by means of non-real objects (as synthetic images and sounds).

### *4.1. Changes in the teleoperation chain*

In the classical instrumental chain, we act on a physical object, which is a part of the physical universe and thus *real*, through a physical interaction, as in playing violin, cutting with a scalpel, etc. Thus, the object is perceived through its mechanical, visual, and auditory properties.

Fifty years ago, the manipulation of dangerous materials, such as nuclear materials, began to implement the need of a distant manipulation, setting-up two different spaces: the user's space and the task's space. As long as the manipulation remains mechanical, i.e. as long as the two spaces are near in space, in time and in nature, there is no problem of Presence. The experimentalist manipulates the block of nuclear matter through a mechanical pantograph, feeling it mechanically and seeing it through the glass that separates the two spaces. When this direct physical communication has been replaced by electrical communication between the two spaces, and both spaces become more and more distant, the immediate and trivial presence disappeared. We can notice that the main property that has been lost is obviously the "materiality" of the manipulated objects, which is, in the teleoperation case, conveyed by physical action and mechanical interaction.

### 4.2. Changes in sensorial data production

In the field of sensorial data production, representation and transmission, any explicit problem of presence appears, when the sensorial data were provided by real objects, directly or indirectly through sensors (microphones, telephones, cameras, etc.). Since the 1950s, with the discovery of Shanon's theorem and its implementation in digital to analogic converters, real sensorial data could be produced, "ex nihilo", i.e. without any real objects, by abstract and non-real entities such as numbers and algorithms. It can be considered that the VR concept started from this stage. In this sensorial data creation process, the question of realism has been a permanent and haunting goal. Most of the experiments already done in VR [7,8] attempted striking realistic visual and acoustical representations. In light of the difficulty of achieving this goal, the question has been progressively transformed in terms of "Presence", of "believability", of "being there" [1] or "conviction of reality" [9] of such synthetic representations.

### 4.3. A unified architecture for telecommunication and teleoperation

With the birth of the two physical and functional spaces described before, the classical teleoperation instrument has been decomposed in three parts: the part which is in the user's space, the part which is in the task's space and the communication between them. Establishing an appropriate communication between these two different worlds means to equip correctly each part of the communication chain.

Firstly, we have to equip both sides with pairs of actuators and sensors that work together, with sensors on one side and their corresponding actuators on the other side (Fig. 2) and vice-versa: from microphones to loudspeakers, from cameras to displays, from mechanical sensors that acquire the user's actions to mechanical actuators to perform these actions. These pairs of actuators and sensors are dedicated for each basic

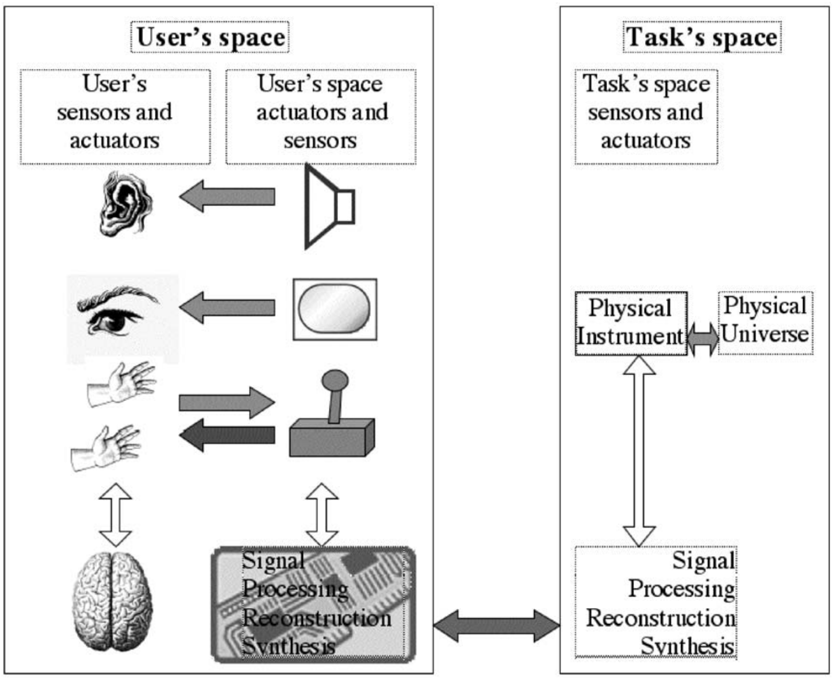


Fig. 2. The complete teleoperation–telecommunication chain.

sensory-motor modality: vision, audition, and action. Thus, the human representation of both realities is split into different pieces that are clearly segregated, according to the used transducers: hearing by means of a specific device, seeing by means of another device, and acting on another one. Thus, the integrity of the reality, constructed by our mental representations, is lost, causing a cognitive break expressed as a lack of Presence of the distant world in the nearest world and vice versa.

Once the representation of these two realities is conveyed by separate signals on each side, layers of signal processing are inserted for each part in order to reconstruct one space in the other. As long as we could have a good mental representation of the distant space, as long as it remains an ‘‘alter ego’’ space, this reduced information is sufficient to restore the feeling of Presence on the second space for the user. Since the real phenomena cannot be entirely reproduced, the user remains faced with a lack of information and the feeling of Presence cannot be fully satisfied. Observing that in the teleoperation chain (Fig. 2), the signal provided to the user could be incomplete, a third module in order to rebuilt in real time the lost information has been progressively inserted, that is typically a computer synthesis system, which handles the creation of the unknown information by inserting virtual objects (avatars, etc.).

At this point, we remark that we obtain a similar platform on both sides, composed of pairs of sensors and actuators corresponding to all the sensory-motor capabilities (for the human on one side, for the physical object on the other) and real-time simulation systems, including signal processing from and to the alternate distant world and virtual representations that are completely built. We can also remark that this platform is precisely what is usually implemented in VR systems enhanced with AR functionality, and creating thus an MR architecture. This VR Architecture can be seen as a generic component that will equip symmetrically the user's space and the task's space, leading to the specification of a general common architecture of all our instruments.

Through the previous analysis, the notion of distant worlds can be extended and unified. It can be understood now, not only in its trivial meaning of distant in space, but in a more general meaning as *sensorially and cognitively* distant from us. It covers worlds that are:

- *Distant in space*: far away such as the other planets.
- *Distant in nature*: hostile environments, dangerous materials for human beings (nuclear materials), dangerous manipulations for the task space (fragile objects).
- *Distant in scale*: too small such as nanoscale, molecular and biological scale or too large such as galactic scale.
- *Distant in time*: the action can be delayed, or only partially accessible.
- *Distant in dynamic*: the dynamic range of the action can be non-adapted to the sensory capabilities of human being.
- *Distant because physically non-existent*: abstract data (statistics, geometry, mathematical patterns, etc.), Computer Worlds.

Finally, the teleoperation chain based on the distinction between user's space and task's space, can be generalized in a distributed telecommunication architecture composed of a set of distant spaces, equipped by and communicating through the MR Architecture described above which can be considered as a generic component.

## 5. Restoring the sense of reality

During the huge quantity of experiments that marked the evolution of our instrumental tools described above, we observe that, despite the quest of high visual realism in synthetic images, visual feedback seems not enough to trigger the feeling of Presence. Often, auditory feedback may be better. Introducing, as in conventional interaction, sensory-motor loops that only link action input data to visual or auditory icons as outputs, may enhance this feeling. But, even in the best implementation of these types of sensory-motor rendering, the feeling of Presence will remain ‘‘asymptotically unreached’’.

Conversely, it is a well-known fact that those who first felt a virtual object through a force feedback device have been immediately convinced by the reality or the presence of such object. Even in the absence of other sensorial returns, visual and/or acoustical, and even if the object was simply or roughly rendered, suddenly, a strong piece of reality undoubtedly emerges for the experimentalist, during this type of sensory-motor experiment. Thus, we may assume that haptic sensory-motor modality plays a specific role in the creation of the sense of presence, and thus in its restoring, while the other sensory modalities could be added to reinforce this feeling [10]. But why? Is this due to the force feedback in itself or to the type of information it conveys?

In this sensory-motor modality, the consistency between action and perception is represented by forces and supported by the matter of the objects. Thus, even though we cannot be sure that force feedback is necessary to trigger the sense of presence, we can nevertheless assume that presence cannot emerge without some clue of materiality, in other words, without some clue of energetic consistency or physically based coherence in reconstructed or synthetic artifacts.

## 6. Illustration through experiments

### 6.1. Presence in musical playing

To validate the previous analysis in the artistic case, we present an experiment that implements playing on a virtual violin, looking for the minimal conditions to render it as believable as it is real. The used architecture is composed of a 5 DOF high fidelity force feedback device that interacts in real time with a simulated physically based model of the musical instrument.

The used force feedback device is a custom-developed manipulator [11] composed of independent bar keys. Each of them is controlled by an electromagnetic actuator linked to a high-resolution position encoder (2 μm). One key is characterized by 20 mm vertical displacement, 10 kHz cutting frequency in force control loop, a maximum speed of 2 m/s, and supports a force of 50 N in permanent regime and 200 N in transitory regime. The device power is greater than the up-to-now commercialized devices where a force of 20 N is hardly exceeded in a small volume that is about the dimensions of the hand.

The morphology of the bow (Fig. 3) is obtained by a mechanical coupling of 3 bar keys. One of them represents the transversal displacement of the bow. The two others control the pressure of the bow on two independent strings. Two supplementary keys are used as fingers to modulate the pitch by modifying the length of the strings. Data transfer and computation take place at 3 kHz sampling rate in reactive mode, so the real-time condition is completely satisfied according to the human reaction time and the time constant of the simulated models.

The physically based model is designed with the Cordis-Anima language [12,13] and it is composed of:

- a simple physical model of strings, discretized in a very small number (about 10) of unidimensional visco-elastic interacting masses that produce only 10 acoustical modes, less than a real string,
- a simple physical model of interaction between the bow and the string, that implements only a simplified non-linearity of the interaction (Fig. 4).

All the professional musicians and acousticians [14] who have tried the experiments, concluded to the believability of the "violin character", pointing to the strong dynamic adapted coupling between this minimal physically based instrument and the player as the critical parameter responsible for the sense of presence of this virtual instrument.

### 6.2. Presence in nanomanipulation

Nowadays, the manipulation of small objects at the nanometer scale, just under the human perception scales, such as carbon nanotubes (CNT), has been done with basic interfaces [15] between the user and the AFM. These interfaces are typically image oriented with any sound rendering. Physicists and biologists have strong difficulties to manipulate CNT, biological cells or DNA with these instruments [16], since they have no feedback from their actions.

We have designed a tool allowing not only to see but also to hear and to feel the surface–tip interaction by joining the VR–MR complete structure. The architecture of the tool is the same that is shown in Fig. 2, if we

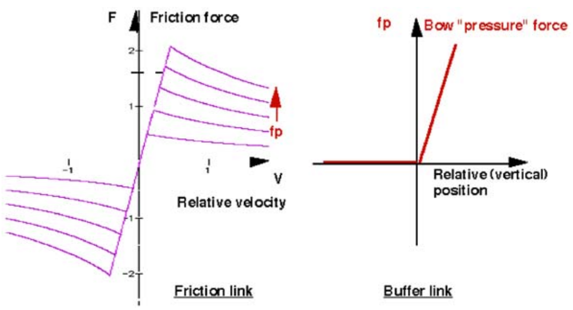


Fig. 4. The bow–string interaction.

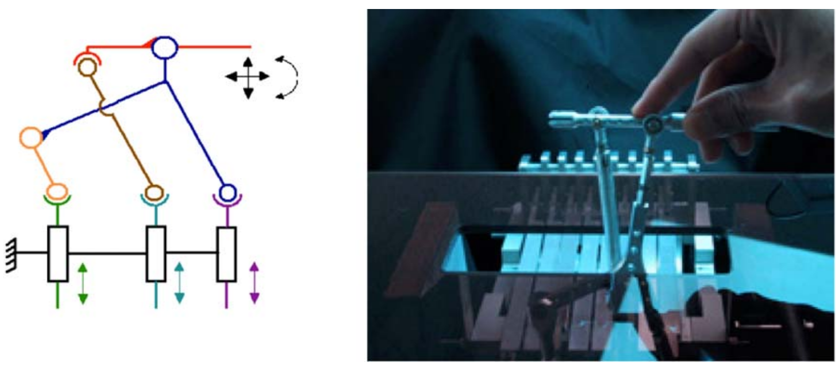

Fig. 3. The force feedback violin bow (left) and the real time playing (right).

replace the physical instrument with the AFM and the physical world with the nano-objects: a force feedback device (FFD) is connected to the AFM through a real-time simulator (Fig. 5), which is also in charge to produce the visual and acoustical feedback from a physically based object simulation.

As a most demanding test-bed, and to prevent the bias of trivial realistic representations, such as 3D representations, we choose to experiment on a basic phenomenon that is the approach–retract interaction. As presented before, this interaction produces a complex hysteresis phenomenon (Fig 1) that cannot be expressed only by the representation of the interacting objects, the surface and the tip. The force and the distance when the AFM tip approaches the surface differ radically from those of tip–surface separation.

According to the assumption that the sense of presence, necessary to steer an accurate manipulation has to integrate a minimum physically based consistency in the representations, we implement a real time simulation of physically based models of the nanoscene. These models are based on the fundamental principles of physical particle-interaction simulation, using the CORDIS-ANIMA language [12,13]. The desired components are modeled like material objects with their specific weights and inertias, that are permanently in interaction with the external environment as well as between them. Data concerning the position information received from the FFD and from AFM act on the virtual model which generates the resulting force data. The same force information is sent back to the FFD as well as to the AFM piezoelectric element after the appropriate signal processing. Using both positions and forces data, visual and sound renderings are created and offered to the experimentalist in addition to force feedback, providing thus an interface that takes into account the full cognitive capabilities of the user.

To guarantee the sense of presence of the interacting objects, AFM tip and nanosurface, we have to take care of the correspondence between the hand manipulation and the visual and auditory representations.

The virtual scene is based on a nanosurface model, subjected to elastic deformations due to the Lennard–Jones interaction that exists between the surface elements and the tip. The tip is linked with the piezoelectric element by a cantilever modeled as a spring. The user can move the virtual piezoelectric element with the FFD and feel the interaction force in real-time. The visual rendering of the approach–retract curve is based both on a geometric representation of the scene, and on a representation of the approach–retract phenomenon, i.e. the evolution of the interaction potentials between elements. The sound feedback strengthens the multisensory rendering and is captured from an acoustical vibrating element that follows the dynamics of an atom of the nanosurface. The best visual representation is not necessary the visualisation of the geometrical appearances, as is in the traditional AFM visual display. For instance, the potential variation in the approach–retract curve can be represented as a ball rolling down into a potential gap (Fig. 6a). This representation is based on the addition of the two potentials: the elastic potential characterizing the cantilever movement and the non-linear Lennard–Jones potential characterizing the tip–surface interaction. Two other visual representations of the same model are shown in Figs. 6b and c.

When the tip approaches the surface, the returned force is null and no sound can be heard since there is no tip–surface interaction. Once the threshold is reached, the tip suddenly snaps on the surface, the hand is pulled down by the FFD and a wind-like sound starts to be heard. At the same time, the ball rolls down to a minimum hollow in the potential representation, trapped onto the surface in an equilibrium position.

Then, the user can push on the surface in the same direction, feeling the stress due to the repulsive behavior of the interaction. In this case, the pitch of sound increases, producing a frequency modulation in the heard sound, that is associated at the same time to the visual deformation of the surface and to the force feedback. When the user tries to pull the $Z$ piezoelectric element and the tip backs out of the surface, the sum of

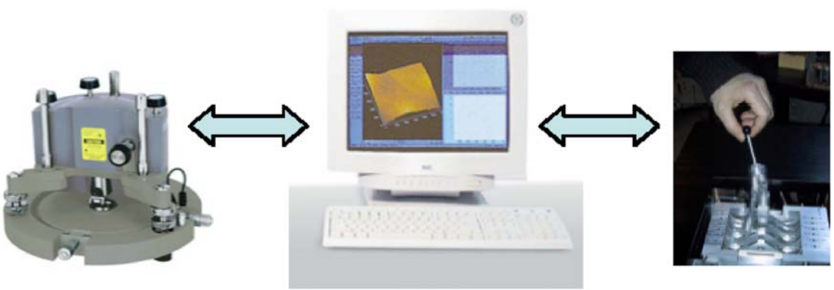

Fig. 5. The architecture of the force feedback Nanomanipulator AFM (on the left). Real time simulator (on the middle). FFD (on the right).

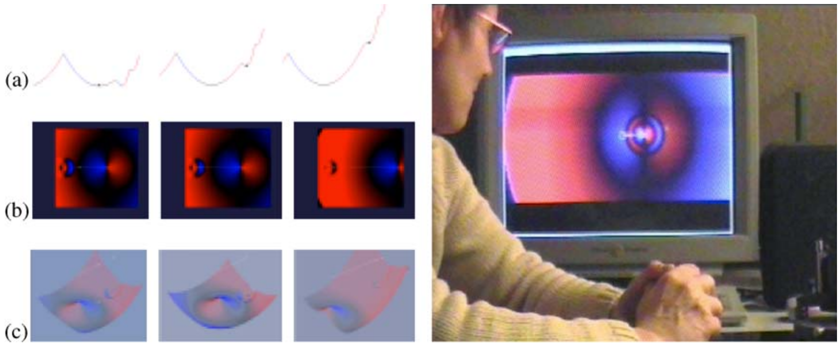


Fig. 6. Visual representations of the hysteresis phenomenon (left) and real time experiment (right).

forces acting on the atomic layer of the surface become null, so the sound gradually disappears. If the user continues to pull the AFM probe from the surface, which corresponds to an attractive interaction, the sound starts again. Its intensity increases according to the absolute force value. The visualization shows the extension of the cantilever, while the potential representation brought the ball higher and higher. When the ball is about to fall in the new hollow (Fig. 6), the spectrum of the sound is completely shifted towards lower frequencies, triggering the feeling of instable regime. The snap-off brings the system back to the original state.

This virtual model allows the user to feel the tip–surface interaction and especially the great intensity of the sticking contact force of the tip on the surface. The use of this virtual model enhances the role of the multisensory feedback and the force reaction between the user and the virtual nanoscene. In the case of the tip retraction, the user experiments a full interaction with the phenomenon, and thus is able to control the tip with an unusual accuracy. For example, we can keep the tip at the snap-off threshold for several seconds, despite the high instability of the system. This accurate manual control is due to the fact that the experimentalist feels, but also hears the sound shift and sees the ball about rolling down. Holding strongly the FFD key, the experimentalist is able to permanently adapt the impedance of his hand, according to his multisensory feelings, in order to prevent the tip to snap-off.

The haptic manipulation, which tightly combines force production and force perception, is placed at the center of this multisensory representation, allowing the construction of a sense of the *dynamic how much*, through the intensity of the forces. The visual rendering of the objects reflects their physical effects in space as force fields, giving a sense of the *dynamic where.* The sonification process has to be placed in its co-ordination with the haptic and vision sensory processes during action, allowing the formation of a sense of *when*, in its correlation with the two others, *how much* and *where.*

## 7. Conclusion

This paper presents an approach of the Presence concept, illustrated by two different extreme examples: artistic instrumental playing and nanomanipulation. After a brief review of relevant concepts in philosophy, it concludes that the question is not a new philosophical as well as psycho-cognitive question. It assumes that the novelty is in the possibility to experiment it with our contemporary instrumental background, based on the multisensory VR–MR paradigm, as generic components of an unified telecommunication–teleoperation system, linking humans to distant worlds, whatever these worlds are. Thus, the analysis of the historical evolution of the instrumental chains, from teleoperation to synthetic worlds, allows to point out the critical transformations responsible for the disappearance of the sense of presence.

However high the level of visual realism achieved today, connecting the visual channel to the action channel is not sufficient to elicit a robust feeling of Presence. The same is true for auditory feedback, even though it enhances more often a deeper sense of reality.

As long as haptic perception is excluded, as was currently the case in most multisensory representation systems, our sense of Presence is limited. But, the core minimum criteria to trigger the feeling of presence of distant worlds is probably not the force feedback interaction in itself but more the content of this interaction, that is the existence of matter, responsible for the dynamic correlation between real sensory-motor events. Thus, the primary property to be instilled in our virtual representations, whatever they are, should be a drop of ‘‘evoked matter’’.

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