Dynamics as common criterion to enhance the sense of presence in virtual environments

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Abstract

This paper is a theoretical dissertation on the role of the matter and its representations through dynamics in the organization of the multisensory space. We assume that the mechanical matter, which originally produces the multisensory-handled events, is an invariant identified from the spatio-temporal correlation between visual, auditory and tactilo-proprio-kinesthetic perceptions. We illustrate this assumption by several examples using virtual objects modeled by means of physically-based formalism, able to produce dynamically plausible and consistent multisensory events. We then examine frontiers between ambiguous notions as: geometry vs. dynamics in visual believability, optical matter vs. mechanical matter in contour identification, interaction vs. morphology or topology vs. force in complex manipulations. We conclude that, a challenge to enhance the presence of virtual objects is to be able to instill in their models a just sufficient clue of evoked materiality using minimal physically-based representations.

Keywords: Virtual objects. Multisensory simulations. Force feedback manipulations. Physically-based models. Dynamic consistency.

1. Preliminary observations

Despite the huge quantity of developments in Computer Graphics and Computer Sounds and Music, allowing to reach a high degree of visual and auditory realism in synthetic images and sounds, this realism seems not sufficient to trigger spontaneously the feeling of the Presence of such artifacts. The possibility to handle them, as in conventional interaction, i.e. to link action inputs to visual and auditory outputs, improves this feeling. But, even in the best implementation of these types of sensory-motor rendering, allowing to say “Yes, very good technical implementation”, the feeling of Presence will remain “asymptotically unreached”.

Even so, this feeling of “imperfectly reached being here” does not exist in front of recorded sounds and images, even if their quality is bad or degraded as in ancient recordings of singers or political speeches. Listening them on old acetate records bring them immediately and emotionally present in our space.

We will assume here that the sense of Presence emerges from the identification of the material object that is behind its phenomenological expressions. This material object is playing as a non pre-existing invariant that will be identified from experienced specific correlations in the sensible phenomena material object.

This assumption is suggested by the well-known fact that the feeling of a virtual object through a force feedback device during its manipulation convinces us immediately of 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. Here, the consistency between action and perception is represented by forces and supported by the matter of the objects, allowing us to assume that presence cannot emerge without some clue of materiality, in other words, without some clue of energetic consistency or physically – based coherence in synthetic artifacts.

2. Is Presence a new question?

The distinction of what is *real* and what is *non-real* is an usual and long lasting question of philosophy as well as of physics. Recently, in his theory of Veiled Reality, Bernard d’Espagnat [1] points out that in Physics, the reality remains intrinsically unknowable in details but the knowledge developed by physicists as description of the phenomena, enlightens the structure of an underlying reality. 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.

No explicit problem of Presence occurs no longer whenever human beings manipulate real objects, directly or indirectly through mechanical instruments. In teleoperation, since objects are mechanically teleoperated, as in the manipulation of blocks of nuclear matter through a mechanical pantograph, feeling it mechanically and seeing it through the glass that separates the two spaces, the immediate and trivial presence of objects continues to be felt by the experimenter. When this direct physical communication has been replaced by electrical communication between the two spaces, the space of the user and the space of the task, the physical continuity of both has been broken causing the lost of the trivial sense of presence of each space for the other.

Similarly, 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 50's, with the demonstration of Shanon's theorem and its implementation in digital to analog converters, real sensorial data could be produced, "ex nihilo", i.e. without any real objects, by abstract and symbolic entities such as numbers and algorithms.

In both cases, the primary properties that have been lost are the same: those that are related to the "materiality" of the manipulated real objects or recorded phenomena produced by real objects.

3. Experimental context, aims and methodology

In the real world, objects are a "single entities" interacting mechanically between themselves, producing correlated changes in each of them, without any input – output causality. Due to the action-reaction principle, it is strictly impossible, to distinguish of whom is acted and whom is acting on. Real objects are not input-output systems. Conversely, there are two cases in which the oriented input-output paradigm is "naturally" implemented: the human machine and the electrical (or electromechanical) machines. In contrast to a physical object, these machines are "broken" into four components: (1) sensors – (2) processing – (3) actuators embedded in a (4) mechanical morphology.

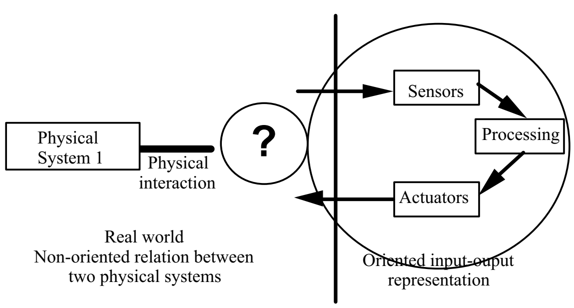

Figure 1. Human-physical world interaction in system representation

Thus, when a physical object "physically interacts" with a human being, two completely different systems are in *vis-à-vis*, one that is not a sensor-processing-actuator system (figure 1 on the left) and one that is (figure 1 on the right). As pointed out by the interrogation mark, the observation of such closed-loop system between these two types of machines (mechanical object and sensor-actuators systems) is not trivial.

Faced to this theoretical difficulty, studies in human action-perception system are usually performed by trying to understand how the multisensory signals received by human sensors and emitted from human mechanical and vocal actuators are interpreted and/or correlated in humans through the neuro-cognitive processing, i.e. by considering only the human side of the entire system, via for example the studies on cross-modal transfers or intersensoriality. Such phenomenological approaches are recently improved by the concept proposed by Stoffregen and Bardy [2] of "Global array" as an ambient multisensory space array considered as a whole. Their general hypothesis is that perception consists of sensitivity to patterns in such global array, more than to patterns in single-energy arrays.

The Gibson's fundamentals [3] of the genuine link between action and perception on the human side could be faced to the Leroy-Gourhan's works [4] who demonstrated that humans and physical world act reciprocally and are modified simultaneously, one by the other.

Replacing the real world by artifacts as those produced by computerized electromechanical machines (as VR is) allows to elicit this face-to-face situation and to experiment it. As shown in Figure 2 (on the left), computerized electromechanical machines are able to represent a real object by an input-output paradigm, similarly to the human machine. They are composed of sensors – processing - actuators in which the computational process through which sensors and actuators are linked necessarily plays the role of a representation of the physical material object.

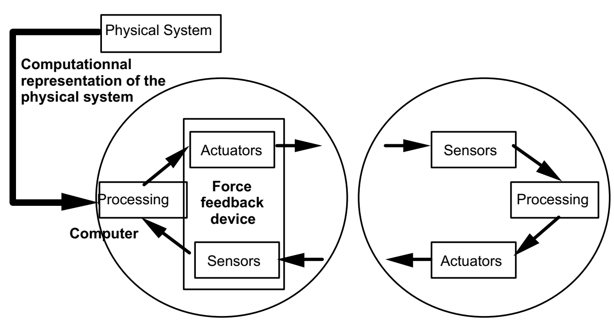

Figure 2. Computerized electromechanical machines as an input-output representation of physical world

Thus we are able to experiment what could be the objective properties of the process that produces sensorial handled data, i.e. what could be the genuine correlation between these data able to trigger the sense of presence and of the believability of virtual or distant worlds. Further, we have thus at our disposal the experimental means to catch the role of the matter as an invariant producing such phenomenological correlations allowing us to address the question of 'how the sense of the tangibility could be cognitively built?".

The methodology we will apply is exclusively qualitative by direct sensible appraisal by users, like that used by a musical instrument maker with instrumentalists. It is more a pragmatic approach of clearly cut user's agreement and satisfaction than measurements approaches [5], either subjective or behavioral. Our methodology is based on "analysis by synthesis" method proposed by J.C. Risset [6] in musical psychoacoustics, or similarly on the "understanding by building" method as proposed in cognitive and developmental robotics [7]. We will build computerized electromechanical artifacts, by means of physically-based models, a priori able to allow us to functionally manipulate the dynamical features. "Functionally" means that physically-based models are not understood as a model of natural phenomena (Physics for Physis[1]), with its correlated feature of realism, but as a formal algebra, able to model relevant sensible observable features of classes of dynamic phenomena in a consistent way.

The methodology of designing such models is based on phenomenological top-down analysis. The first stage of the modeling process is to specify these relevant dynamic features.

The first stage is then to specify a minimum set of sensible patterns that could be relevant to address the tangibility of the underlying material causality from the observation of sensorial events. The second stage is to generate this set of patterns by a simulated physically-based model and to verify objectively if the produced artifact renders them correctly. Finally, we verify qualitatively, through unanimous answers, if these patterns play cognitively and perceptively the same role as analyzed previously in reality, during the specification stage.

4. Role of the matter in images, sounds and actions

4.1. Geometry vs. Dynamics in visual events

Except in images produced exclusively by geometrical processes (geometrical drawings or synthetic 3D images), in all other cases, images engrave motions. Even if objects are at a greater scale of time than usual evolving phenomena such as mountains, trees, etc., expressing the immobility, we can remark that the morphological features (the shape, the texture, etc…) contain more or less explicitly the trace of the evolution. Look at the figure 3 that shows (1) a fossil shell, (2) a geometrical representation of the fossil shell with a logarithmic spiral. It appears clearly that in the photograph representing the shell, the trace of the time is explicit and is a relevant feature in the interpretation of the object as a real object. The immobility itself has to be seen as a state of the motion. The major difference between the photograph of the shell and its geometrical representation is that the time is completely absent in the last. This difference sparkles to our eyes by means of very small details as the local variations of the shape that point out the fact that, engraved in this shape, a physical evolution (the fossilization) happened with its spatio-temporal random features. Thus, if we want to produce a believable virtual fossil, must we emphasis the geometrical organization of the shape or the features that address the labor of the time?

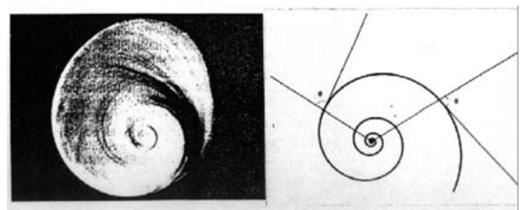

Figure 3. Dynamics vs. Geometry

From this observation, it appears that the critical frontier in visual representation is not the distinction between morphology (shapes) and rendering (light) as usually considered in Computer Graphics, but between optical matter, represented by electromagnetic field, and mechanical matter represented through forces, in which the first produces pure visual features (color, shadows, etc.) and visual shape and the second produces mechanical shapes and motions. Visual features are then related more to the geometry of the space, since mechanical shapes and motion have to be represented by dynamics[2].

4.2. Optical shape vs. mechanical shapes

In the previous paragraph, shapes are on the two sides of electromagnetic features and of mechanical features. This points out the underestimated ambiguity of the notion of shape. Shapes are usually considered in their geometrical features and so speaking they can be extended to all the spatial properties exhibited by an object: shape, size, orientation, and texture considered as micro-local properties of the contour of an object. There is a lot of work addressing the question of the recognition of such parameters, the considered senses being the sight and the touch. It is often considered that except the texture that is sensed equally by the touch and the vision, the others are more reliably encoded by the visual than the haptic system [8]. Developmental psychology points out other results as those in very young infants, when transfer from touch to vision and not from vision to touch is observed in the recognition of shapes (prism or cylinder).

Does it mean that there are two notions of shapes, one purely geometric, more related to vision, and another "physical", more related to resistant matter, the texture

[1] "Physis", in ancient Greek, means Nature, as "Being given (to the humans)". "Mathematé" means "being done (by the humans)".

[2] In ancient Greek, "Dynamé" means "forces" and "Kinema" means "motion". Dynamics is a representation of systems that generates kinematical behaviors.

being the frontier between the two spaces? Indeed, shapes have, as the Janus figure, two faces or two determinants. They emerge from two completely different processes, optical and mechanical, and thus, a single object can paradoxically exhibits several shapes, or several "contours": the visual shape and the mechanical shapes.

More, the visual shape and the mechanical shapes of a single object have no reason to be always identical. Several situations illustrate this paradox. A rainbow or the mirage of an oasis in the hot desert has a visual shape but doesn't have mechanical contour. We can traverse them or walk through them. Conversely, a perfectly transparent door has not a visual contour but has a hard mechanical shape. The visual shape is sensed by eyes whereas the mechanical shape is sensed by the body.

Basically, the visual features are nothing else but the singularities of the interaction between photons and electromagnetic matter. The visual shape (the visually detected flatness, the visually spherical shape etc…) is the geometrical locus of the spatial singularities of the interaction light – optical matter. Thus, visual events are intangible. Other classical examples could be geometrical drawing and synthetic 3D images produced by pure geometrical representations.

In usual rigid objects, the visual shape seen by the eyes is at the same spatial location as the mechanical shape "seen" by the body. Although these objects are usual, nevertheless, they represent specific cases where the matter is 100% (99,99%) mechanically rigid and simultaneously 100% (99,99%) electromagnetically rigid (opaque). But what about flames, rainbow, water, fluids, translucent pastes, glasses etc?

Furthermore, what about objects like cat fur or hair, that are not 100% (99,99%) mechanically rigid, and thus exhibit several mechanical contours. In other words, and in a funny way, all what it is happening in terms of "contour" as a primary cue of space organization, depends on the percentage of the optical and of the mechanical rigidity.

More, a thing that could be considered as a single object can exhibit several mechanical contours. If you put a force sensor on the palm of the hand when stroking your cat, the force detected will be very low when the hand is in the fur, higher when it is on the deformable skin and higher when it is touching the skeleton. This means that a single entity - your preferred pet - may exhibit several mechanical contours, described by several thresholds in the singularities of the physical interaction.

4.3. And what about sounds in the believability of virtual objects ?

Audition is, as vision, exteroceptive perception. It is why, in Virtual environments, the sounds are often used for the localization of sound sources through 3D auditory representations. But sounds convey another basic function: the identification of the mechanical properties of the sounding object (heavy, light, resistant, deformable, metal, wood, paper sheet, etc…) and of its interaction with the physical environment (more or less hard shocks, sticking collisions, friction, etc…), in the aim of recognizing the objects as well as their evolution (triggering, stopping, pursuing, etc…).

This function is widely studied in computer music and in digital musical instruments [9][10]. It is underestimated in Virtual Environments as well as in psychological studies, which prefer to point out the role of the audition in abstract activity as the discrimination of numerosities [11][12], and consequently its link with the vision.

Sound does not exist without mechanical matter with inertia (not neutrino) and minimal rheological properties, as at least elasticity. The minimal system to produce sound is a second order differential equation system. Sound is the mechanical behavior of an inertial and rheological matter and its morphological and topological organization. It encodes in a single signal all the properties of the material object. In addition, it conveys all the properties of this mechanical matter: material, structure, etc… on the larger spectra of temporal characteristics (from some Hz to several tens of KHz). From this point of view, it is the best "distant" and "diffuse" representation of what the material object is: a kind of "exteroceptive sense of touch".

4.4. Interaction as exchanged actions

Action is the modality that had been deeply transformed with the electrification of instruments. In computerized environments, action started with interactivity. Since Evans &Sutherland who introduced the manipulation of virtual objects in 1963 [13], the computer interactivity has had huge developments. Nevertheless, since the introduction of force feedback devices, the action has been restricted only to one type, called by C. Cadoz "semiotic function" [14][15], in his typology of gestures. This typology analyses the gesture according to three functionalities:

• The semiotic function: A pure semiotic function appears in action during which the tactile-kinesthesia perception of an external object can be neglected, as it is the case in : free gestures, pointing, sign language, gestures which accompany the speech, the gesture of musical conductor, etc…

• The epistemic function: a pure epistemic function appears in the pure tactile activity to know objects: contours, texture, orientation, temperature, etc. The associated action is mainly an exploratory action, characterized by the fact that the energy produced and exchanged with the explored object is negligible [16].

• The ergotic function appears during a sensory-motor activity in which the physical energy exchanged between the two interaction bodies (human and manipulated objects) (1) is not negligible in the performance and (2) is engraved in the produced phenomena. For example, in the pointing gesture or in typewriting, that are pure semiotic actions, the dynamic of the gesture is not usable for the aim of the action (pointing, typewriting). Similarly, the palpating of an object does not transform this object. Conversely, when we are molding a paste, the dynamic of the molding is engraved in the paste. When we are plucking a guitar string or when we are bowing a cello string, the produced sounds engrave (or encode) the dynamic of the action as well as the energy exchanged between human and objects, as a main feature of the sounds. Differently from the epistemic and semiotic functionalities, ergotic functionality cannot be implemented without mechanical matter.

These three functionalities – semiotic, epistemic, ergotic - are more or less merged in usual actions. Nevertheless, in computer environments, the most part of the developments are devoted to the development of devices and processes either for the semiotic function (pure sensors as sticks, keyboards, mouse, motion capture devices, etc…), or for the epistemic function (tactile devices, haptic display, data haptization). In the hypothesis of the central role of the matter (or the material features of the world) in the recognition and in the mental reconstruction of the tangibility of virtual or represented objects, the ergotic function will have to play a central role. The transducers able to convey this ergotic interaction are only the force feedback gestural transducers.

4.5. Sounds, Shapes and Images relations

And what about sounds, shapes and image relations? Having in mind that sounds represent better than vision and like touch, the inertial and rheological properties of the matter, it can be assume that a genuine link between sounds and action may obviously exist. They address directly the same mechanical matter. Such genuine link is more difficult to elicit in visual events and action, due to the nature more immaterial, and perhaps then more symbolic (as the structural topology identification) of the optical cues.

5. Experiments by means of Virtual Physically-based Objects

5.1. Methodology in sound believability : the basic experiment of the "little coin"

To illustrate the methodology, we describe only an example, made by Claude Cadoz in 1978, and called the little "coin". The first physical particle model we designed is composed of a small 1D punctual mass falling on a simple ground modeled only by a 1D fix point and a visco-elastic buffer, that is a physically-based representation, of a second order collision. The simulation ran at 20 KHz. When the mass shocks the ground, the last deforms at the acoustical frequencies and we expected that the produced sound was the simple sound of rhythmic bounces. But surprisingly, this sound was composed not only of the expected series of the auditory rhythms. At the end of bounces, the sound exhibits a frequency modulation, impossible to obtain with only temporal sequences of bounces. This frequency modulation is provided by the fact that when the deformation of the ground is at a similar amplitude of the bounces (very small, the two objects are sometimes stuck, constituting a single object with other vibrating mode. This phenomenon is a very discreet feature, which exists in real sounds, and that plays the role of the subtle signature of the interacting objects. Several times, we played this sound surreptitiously when people were in the office, and all of them spontaneously were looking at a coin falling in a glass bowl.

5.2. Experiments in the believability of multisensory-handled virtual objects

5.2.1. Experiments in haptics and sounds

The two following experiments (Figure 4) show a minimal model, which allows to produce in real time believable glass-finger friction sounds and bowed strings sounds on all the range of the manipulation. There is a lot of acoustical models for this type of phenomena. They focus on the complex rosin material that regulates the sticking between the two objects. These models are very complex and they are used, as the physically realistic models of strings, to design real objects. Nevertheless, they have never been able to render all the sensible and complex modulations appearing during performance: timbre modulation, pizzicati, way of attacks, creaking, etc. A simple model as been designed, not focused on the realistic reproduction of the morphological properties of the objects themselves but on the interaction between the surface (resp. the string) and the hand, through a simple non-linear friction model modulated by velocity and pressure. The force feedback device is a 2D stick, 1D for the velocity and 1D for the pressure. It moves only on about 5 cm. The surface (resp. the string) is simply represented by a very few number of uni-dimensional masses linked by simple uni-dimensional visco-elastic constraints.

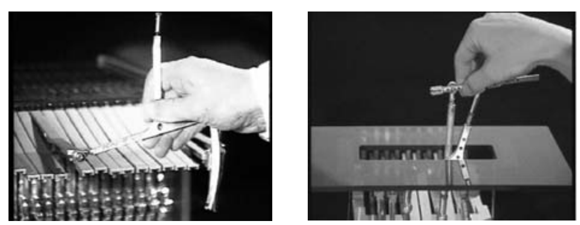

Figure 4. Minimal physically - based models for haptics-sounds Presence

The model focuses on the closed-loop between player and object, with a high quality of reactivity (less than 0,3ms between the device inputs and force outputs). Thus the morphology of the friction is completely different than in real situation but the basic features of dynamics of the interaction are rendered.

Several professional musicians and acousticians [17], as well as several novice people who have tried the experiments, concluded unanimously 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 presence of this virtual instrument.

5.2.2. Experiments in haptics and vision

➢ Paradoxical matter

The following simulations (Figure 5) illustrate that “an impossible matter” (i.e. a matter having rheological parameters not possible to implement in the real work), is considered as a true matter, when the physico-visual experiences exhibit consistent physical behaviors in time.

On the upper row, simulations are of a matter that is too hard to really goes through the bottleneck (the forces felt by hands are very high) although the deformations can be very large. On the lower row, simulations are of matter that is too soft, too much fluid to be felt by fingers. The feeling is very delicate. According to the energetic consistency that is clearly revealed by the visualization as well as by the feeling of the force, this non-realistic object seems unanimously possible and “real”.

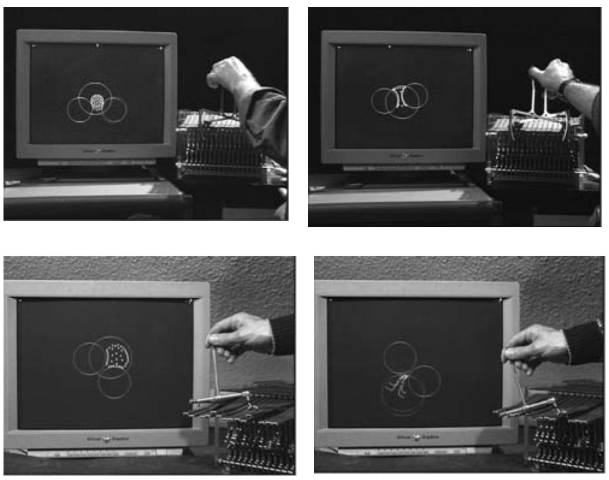

Figure 5. Paradoxical matter

➢ Obstacle guiding and avoidance

In this experiment (Figure 6), a user is guiding a small physical simulated train, with a lot of DOF, by pulling it from its “nose”, in a labyrinth composed of rigid obstacles and a straight free way.

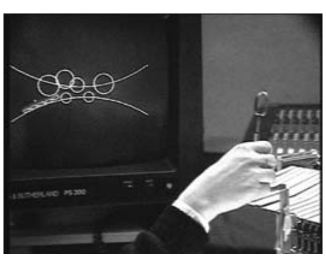

Figure 6. Vision as a sense of topology and force as a sense of physical global state.

The complementary of the vision and the force is emphasized. When the little train is blocked in the labyrinth, the force, which integrates all the behavior of the train on the manipulated point, indicates how much the little is blocked. The experimenter knows immediately if he can push (or pull) or if it is worth trying. But it is unable to indicate where are the blocking points and to find strategies to get out. Conversely, the vision shows on what segments of the train this blocking occurs, allowing him to define strategies of driving. It allows to identify the topological features of scene, that are features more abstract than geometrical ones.

5.2.3. Experiments in haptics, audition and vision

➢ Anamorphosis of the action and force feedback

The following experiments show that the morphology of the manipulation and of the visual space can be different according to the presence (or not) of a force feedback. The two simulations represented on the left and on the right of the figure 7 are the same. They are composed of small sharp pyramids moving in a ball manipulated by hand with force feedback. Only the morphology of the manipulation differs.

On the left, the co-ordinates (x, y) of the sphere are manipulated by two independent keys that are displaced vertically. The motion of manipulation is non-usual and it is very different of the visual motion of the sphere. On the right, the manipulation is by means of a 2D stick and the motion of manipulation is similar to the visual motion of the sphere. Without force feedback, the first manipulation (left) is impossible, as in the game in which we try to draw by manipulating two independent knobs. But, when we added a little drop of consistent force feedback, all the experimenters perform accurate manipulation of the ball and of the pyramids.

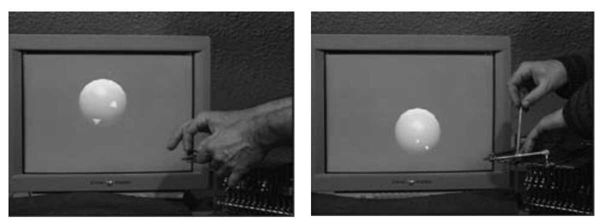

Figure 7. Two morphologies of manipulation: different (left) ant homothetic (right) to the visual motion

More surprisingly, in such situation, the manipulation is more accurate than with the second (right) with usual morphology: in the first case, persons are able to control the shocks of the pyramids on the ball producing expected auditory rhythmic sequences.

This means that in the presence of a sufficient energetic consistency between all the multisensori-motor events, the manipulation that allows to feel it more precisely, leads to more accurate manipulation. That is the case when the two coordinates are manipulated separately, the two components Fx and Fy of the force being also felt separately.

- The little bouncing grains

The following pictures (Figure 8) show two similar experiments in which little objects are moving inside a ball manipulated by hands with force feedback. The shocks of the grains on the ball produce sounds. On the left, the simulation was made in 1989. The visual quality of the image and the acoustical quality of the sound are low. On the right, the simulation was made ten years after in 1999 with a better rendering of image and sound. These experiments show that the quality of the sound and of the image does not increase the believability of the represented scene. More, the new visual rendering (on the right) underlines the synthetic images, revealing the artificial process and thus, the scene is said technically speaking better than the first but not more believable.

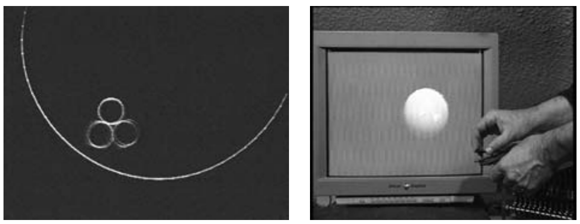

Figure 8. Believable dynamics vs. realistic rendering

- The force feedback multisensory nanomanipulator

The experiment shows in the figure 9 is a manipulation of a complex phenomenon that occurs during the approach-retract of the atomic force microscope probe to a nanoobject. This approach-retract is a non-linear hysteretic phenomenon, with two zones of instabilities. It is difficult to manipulate this type of phenomenon without sensory feedbacks.

Figure 9. Multisensorial physically - based artifact to improve real tele-manipulation

We implemented a virtual simulacrum of the real scene, that runs in parallel with the real manipulation with force feedback, and which returns energetically consistent correlation between action, force feedback, sound and visual deformations. The manipulation can then be performed with a significant decrease of bad trials. This multisensory - action platform is currently used in student's teaching.

5.3. Come back to visual representations

As stated at paragraph 4.1, even in pure visual representations, the question of what is the features able to trigger the sense of Presence. As a result of the extensive developments in computer graphics 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 cognitively unsatisfying. Consequently, works in Computer Graphics were thus oriented in non-photorealistic representations. Our assumption being that believability does not reached without motion (even if in its immobility stage), we have to design models in which the consistency of the dynamics appears clearly and optimally (economically).

The following pictures (Figures 10 and 11) show minimal physically - based particle models of complex physical phenomena: granular materials (figure 10, up), turbulent fluids (figure 10, down), pastes (figure 11), which are usually considered as difficult to implement and to calculate. These models have been designed by firstly taking into account only the dynamics features, as dynamic of piling, of avalanches, of collapses, of turbulences, of curling etc. [18]. For this purpose, physical particles models have the strength (that it is obviously considered in shape modeling as a weakness) to implement minimal geometry (points only without neither volume and nor rotations). The animations as well as the static minimal non-photorealistic representations (only by points) illustrate clearly that the motions are convincing in all the range of the phenomena (they are not one shot phenomenon rendering), and that they reveal an underlying plausible object.

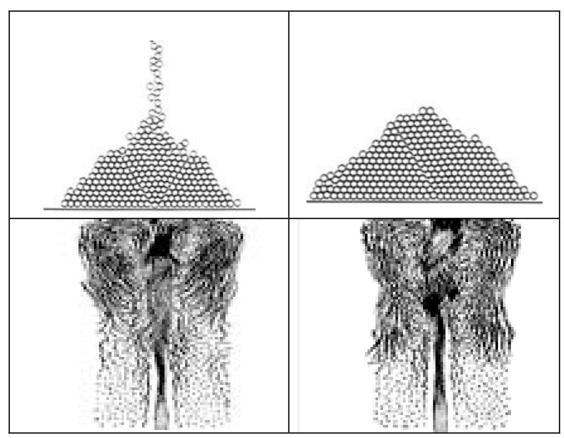

Figure 10. Dynamics vs. geometry (2)

All these models are (1) able to run on real time, and (2) to be controlled consistently by gestures, which increase the believability of what it is represented.

In addition, the more photorealistic rendering shown on the right cell of the figure 11 illustrates that the plausibility is not drastically increased by the visual realism: the image is obviously better but the plausibility of the underlying object (i.e. the presence of it) is of the same level.

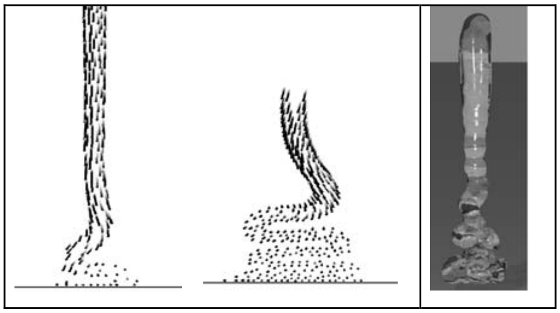

Figure 11. Dynamics vs. Geometry (3)

6. Conclusion

This paper presents an approach of the Presence concept, based on the assumption that the dynamics, representing the matter's behaviors, that produces multisensory events under manipulation, plays the role of the invariant identified during action-perception experiences of the objects. This leads to put the emphasis more on specific consistent correlation between the multisensory-handled events than (1) in each sensory feedback or (2) in arbitrary purely phenomenological correlation between them. It points out the role of new computerized electromechanical technology as those implemented in Virtual Reality, that allows to represent real physical objects as an input – processing – output system in which the computational process can play the role of the representation of the physical object. The methodology applied is this "understanding by building", allowing to create physically plausible artifacts representing a priori hypothesis on the relevant features able to trigger the sense of presence. Physically-based models of multisensory-handled events have been made to explore (1) the genuine link between gesture and audition through dynamics and mechanical matter (2) the believability of impossible material, (3) the robustness of the manipulation to the morphological changes in presence of force feedback and energetic consistency, (4) the bias introduced by synthetic images representations in a coherent multisensory (vision-audition-touch and action) situation and (5) the possibility to built sufficiently believable multisensory-handled artifact to drive complex teleoperated tasks.

In conclusion, the core minimum criterion to trigger the feeling of presence of virtual or represented worlds is probably the existence of matter, responsible for the energetically consistent dynamic correlation between all the multisensory-motor events produced by the object. Thus, the primary property to be instilled in our virtual representations, whatever they are, should be a drop of "evoked matter" using dynamic models designed to represent the just sufficient relevant physical consistency in the produced multisensory sensible phenomena.

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