Hands-on Nanosciences

Joël Chevrier, Annie Luciani, Florence Marchi, Jean-Loup Florens

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J. Chevrier [1,2], A. Luciani [2], F. Marchi[1,2], J.L. Florens[3]

1: Institut Néel, CNRS/Université Joseph Fourier, 25 rue des Martyrs, BP 166, 38042 Grenoble cedex 9, France
2: ESRF, 6 Rue Jules Horowitz, BP 220, 38043 Grenoble cedex 9, France
3: Laboratoire ICA, INPG, 46 Avenue Félix Viallet, 38000 Grenoble, France

Abstract: The nanoworld is invaded by human technologies but remains foreign to our perception and action. Discussions about "nanos" in the society ask for knowledge dissemination in population. Simultaneously, scientists in biology, chemistry... need tools to directly manipulate single nano-object. Both aspects can be now addressed by coupling real time multisensory interfaces to advanced sensors and actuators, either real or virtual. Man exploration and activity at nanoscale using this instrument need a real time transformation of nanosensor data collected and of manipulator actions on a virtual scene. That this system enables one to adapt its senses to nanoworld for discovery and action is the challenge at the heart of this research.

Keywords: Nanotechnology, Education, Virtual Reality, Haptic, Multsensory interfaces

1. Introduction

Nanotechnologies are developing both in research laboratories and in companies. This is a worldwide development. It is characterized by direct action at very short dimensions such as the transistor size which has now the dimension of a small virus, very close to the molecular level. Before, our actions at these scales were more based on statistical treatments. Action of drugs in medicine often involves side effects partially due to their large dissemination in bodies and therefore a relative poor efficiency as a limited part really contributes to the curation. Nowadays, the aim is to act, produce, manipulate, measure, image at the nanoscale in detail, with a large efficiency at the human scale in many different fields: medicine, information technology, renewable energies, environmental monitoring...

These techniques are new. They are more and more inserted in our environment and gradually made less and less visible. This raises many questions. Nanotechnologies after nuclear industry and applications of biology mainly to agriculture are the subject of social debates. No surprise, a general audience rapidly observes that beside the benefits of new usages, it has a poor understanding of nanotechnologies and of the induced consequences.

Classical scientific education does not appear to have adapted tools to face this challenge that even question our representation of the reality. Although in the past, a very large educational effort has been done for electricity and to establish our certitude that matter is made of atoms, this is very difficult and we certainly need a specific effort to provide an access to the knowledge of nanotechnologies. This is a gigantic effort at the worldwide scale that has now been started [1,2]. Results presented here are part of our research program that is inserted in these initiatives [3].

We propose a new pedagogical strategy that uses advanced real time multisensory interfaces to give access to realities in nanotechnologies on the basis of human direct perception. Starting with our installation at CCSTI Grenoble and at Expo Nano Cité des Sciences Paris [4], we here describe how this strategy when adapted can be both uses for a general audience and advanced students on a specific problem: the mechanical contact at nanoscale. We then consider how this could be extended to other specific concepts in nanosciences.

A first and important observation after these experiences with a large audience or students is that haptic interfaces that carry our energetic relation with matter are important in this strategy. Visualisation is not sufficient and cannot supplement others channels of perception if our strategy is to be applied. However it must also be emphasized that to be of interest, haptic interfaces must be of high quality. This means large bandwidth, accurate positioning and large apparent stiffness so that touching a virtual wall using through this instrument is made realistic [5].

The required performances for education naturally connect to the building of demanding laboratory instruments such as a mechanical nanotweezer. A multisensory interface connected to Atomic Force Microscopes is now being designed by our group to manipulate objects, biological materials, large molecules at scale close to 100nm [6].

2. Contact at nanoscale: Expo Nano instrument.

2.1 The context

Expo Nano [3,4], a collaboration between the CCSTI Grenoble and Bordeaux and Cité des Sciences Paris presents many aspects of Nanosciences and Nanotechnologies to a large audience. Beside more traditional ways of presentation, it has been decided, for the first time to our knowledge in such a context, to propose a force feedback system coupled with visualization and sonification to give many people the opportunity to directly experience a key aspect of the nanoworld. The combination of these three feedbacks is essential to perceive all the complexity of this highly non linear behavior of the contact at the nanometer scale [7].

The rule was that no previous knowledge was required [8]. Only helped by real time human perception, everybody should discover and explore a central aspect of the nanoworld within a few minutes. This time scale is imposed by two constrains. First there is a practical constrain. During a public exposition, it is hardly possible to propose a face to face module that must be used a longer time than few minutes to obtain a result. Second a longer time would lead to a much more complex presentation that would not be suited for a general audience. A short time of use means that pedagogical strategy is based on a discovery process more than on a gradual understanding. The needed duration of manipulation is certainly an important aspect in building these applications and it certainly deserves a deeper scientific and careful analysis. Such a system that must be used a longer time with much larger ambitions is now used by more advanced students in science. In that case, students use it during approximately two hours with much more sophisticated strategies and objectives.

Figure 1: Expo Nano virtual nanomanipulator: anybody with no pre-requisite knowledge can explore and discover details of object interactions at nanoscale.

2.2 Virtual nanomanipulator principle:

The presented nanomanipulator (see figure 1) introduces anybody to a single but key aspect of the Nanoworld: the attractive non contact interaction between any objects whatever are their structures. The range of this interaction is a few nanometers. It has therefore a tremendous importance at the nanoscale (chemistry, biology, SOITEC technology for the silicon wafer bonding) but it is absent at the human scale although it appears in the behavior of insects. Animals such as the gecko lezard now appears as a celebrity in the field of nanotechnology because they are using this attractive interaction to walk on the walls.

The importance of this attractive interaction has been enlightened by Richard Feyman in the first pages of his Lectures on Physics (1964) [9]: *«If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis that: All things are made of atoms-little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.».*

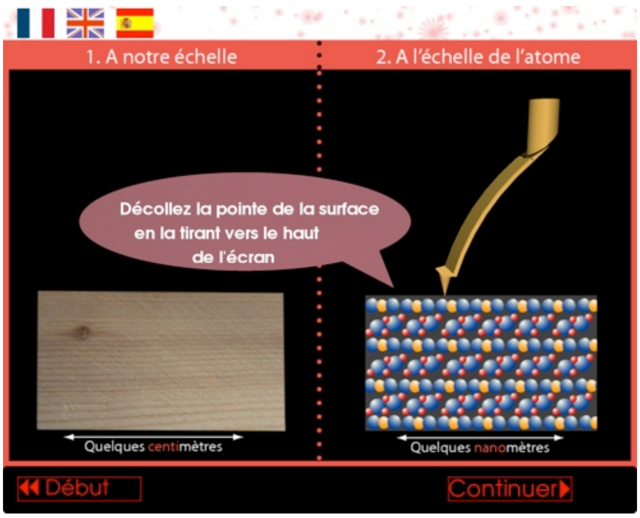

Figure 2: An elastic lever is manipulated so that the user can experience: i) on the left part of the screen, the usual contact (no non contact interaction and direct contact prevents any spatial overlap between objects), ii) on the right part of the screen, if macroscale contact characteristics are still present, a strong non contact is acting that challenges the positioning control imposed by the user and finally results in a mechanical instability that cannot be avoided by the user. This screen is the one seen by the girl in figure 1.

This system has now been used by about 10000 people in different places such as the Cité des Sciences Paris, the CCSTI Grenoble, the CCSTI Bordeaux and the Globe at CERN Genève during months of exhibition. Although this is an encouraging result, a more scientific analysis of these presentations is needed and under way. Definite conclusions cannot be made yet. This article shows the tools we have developed and where we want to apply them. Strategy here applied is however well defined: no a priori knowledge is required. Anybody should suddenly face the fact that our daily interaction with objects is not universal and only based on direct contact. To the contrary, long range interaction can dominate with effects having enormous consequences on matter organization at these scales.

3. Contact at nanoscale: university version.

Contact at nanoscale is so specific that it is indeed an important effect in matter organization as quoted by R.P. Feyman. It therefore is a key point in the design of instruments such as the Atomic Force Microscope that is nowadays used by thousands of scientists, technicians and students in many different fields (biology, chemistry, metallurgy, glass industry,...). When studying the mechanical behavior of a living cell, it is widely used [10]. A detailed understanding of these machines and the associated scientific investigations that are numerous is usually based on specific lectures that are adapted to the audience. This means an interdisciplinary approach which is known to be very difficult and only partially solved by extensive uses of necessary practicals.

We then have developed more sophisticated scenario than the simple presented before so that the multisensory interfaces is adapted to a multi representation of the same problem. This is shown in the following figure.

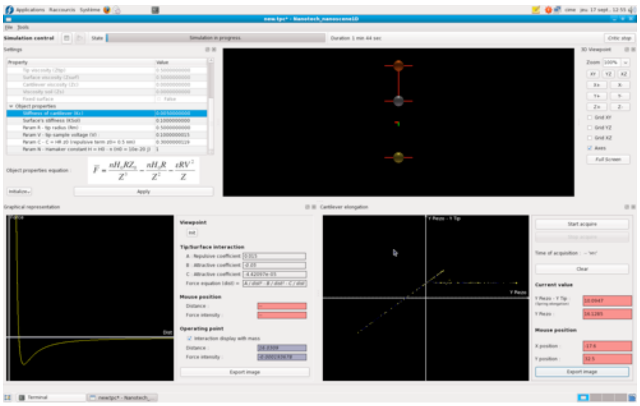

Figure 3: Tools available in real time on screen and combined with haptic interface and sound. Student can change off line the parameters in left corner and uses any combination of the three representations (see text). Haptic and sound connection to the virtual scene are always present. Again a full picture of the system and the user would be very close to figure 1. Real time multisensory interface is also essentially the same [11].

The key differences with the Museum application described in the previous paragraphs are: i) instead of defined parameters that cannot be changed by the user, access is given to a list of selected and relevant parameters that control the interaction at nanoscale, ii) beside the use of the haptic interface and of the sound, the user can organize the visual presentation. Three screen can be selected and combined. One is the presentation of the virtual nano-scene with the elastic lever and the chosen surface. The second is the experimental results that would effectively be measured by the Atomic Force Microscope as user manipulates. The third one is the real time operating point in the representation of the model force that determines the attraction and the repulsion at large distances. Guided combinations of these three screens with the real time nanomanipulation based on the multisensory interface gives to many students a personalized tool that can adapt to their background so that they can built a specific and useful knowledge of this instrument. As the machine can now be put in student hands for daily operation, pedagogical strategies will be further developed and evaluated. It has now been first tested with students of the European School on Nanosciences and Nanotechnologies and will be further developed for many education programs on Nanosciences.

4. Conclusion: future directions.

The previous description focuses on the contact at nanoscale, on the possibility for a general audience and for students using a virtual AFM coupled to a real time multisensory interface to acquire a new knowledge of this important effect.

Two others aspects can be addressed.

Is it possible to build up a nanotweezer based on the coupling of real Atomic Force Microscopes with this interfaces. Such a program has now been started by different groups [12]. Together with the European Synchrotron Radiation Facility, we are now building such a machine in order to manipulate living cells, large molecules and to control their position in the X ray beam time with no induced mechanical damages [6].

Nanotechnologies are based on a large diversity of effects described by biology, chemistry or physics. We believe that the here described approach applied to the non contact interaction should be extended to more effects for the same audiences. Thermal energy combines with chemical reactions at the molecular level in cells to make our muscles working. Electrostatic interaction is important at nanoscale and barely directly experienced at our scale. Confinement of electrons is central to nanoelectronics and to nanooptics and to associated applications such as ligth emission or the ultimate transistor. Confinement imposed to particles either opposed by electrostatic effect, thermal kinetic energy or quantum zero point motion is a central aspect of single particle manipulation in nanosciences. It is a challenging project to propose scenario that can provide a tool to people so that they can discover key aspects of these effects on the basis of their perception first.

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