Mechanical Haptic Nanotweezers

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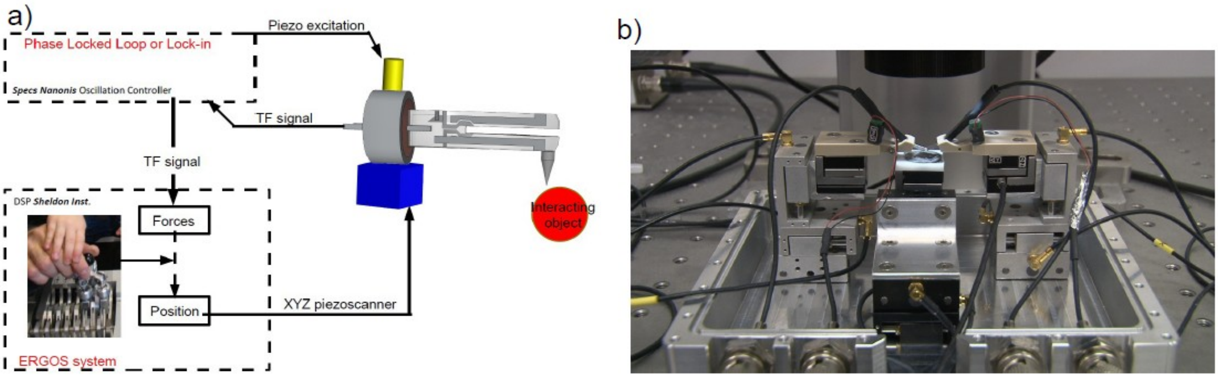
Scanning probes microscopies have been intensively used to study the physical and chemical properties of a wide range individual nanostructure in interaction with a surface; in parallel SPM have demonstrated their capability of nanotools to manipulate and fabricate nano-object. More recently, scientists working in biophysics have combined AFM with optical technique (as fluorescence) to obtain on the same part of the sample a morphological characterization coupled to a classical biological characterization[1]. However, these working configurations do not permit to distinguish between the intrinsic properties of the nanostructure from the ones due to its interaction with the surface substrate and real manipulation in three dimensions are restricted to specific nano-objects. To overcome this limitation, several group have developed mechanical micro-grippers based on MEMS technology to work in vacuum, in air or in water[2]. Thanks to these micro-grippers, full 3D manipulations of submicronic and nanoscopic object have been successfully performed. Nevertheless, to exceed the strong limitations imposed by classic mechanical micro-grippers, namely approximate control of the applied forces and necessity of working under Scanning Electron Microscopes for visual guidance, we developed nano-tweezers based on two independent Scanning Force probes and controlled via a haptic multi-sensorial interface (figure 1a).

Pioneer works on the development of a dual SPM probe head to perform 3D manipulation of micronic objects with a permanent force measurement relied on the two standard AFM probes with a classical optical detection of the cantilever movements [3]. This first design of mechanical nanotweezers is not compact leading to strong difficulties to combine it with an other analyzing technique as X-ray or laser beams. In addition due to the cantilever compliance leading to mechanical instabilities, the operator can not set the working force in the full range of the tip-object interaction. As the ultimate goal of our mechanical nanotweezers is to nanomanipulate object in 3D under a X-ray beam, we selected quartz tuning forks provided with etched tungsten tips as nanofingers (figure 1a).The high quality factor of the tuning forks (Q~10000) and its strong stiffness (*20-40 kN/m*) offers high signal and spatial stability and high sensitivity in the detection of the tip-surface interactions. In addition, this kind of AFM probe have been already successfully implemented on a X-ray beamline to perform AFM imaging and indentation on Ge microdot in order to measure dot Young modulus [4] .

Each finger of the nanotweezers head is mounted on a 3D (XYZ) towels with two open-loop stages, one dedicated to rough displacements and the second a minitritor to the fine displacements (figure 1b). Thanks to a dual specific electronics module from SPEC connected to the nanotweezers head, each nanoprobe can perform classic planar AFM imaging. They have been also used to explore each other in 3D thus providing spatial localisation of their apex. This result opens the way to real «two-finger» nano-tweezers actions as manipulation at the (sub)micron scale. To test the capabilities of our device, a polystyrene sphere of 1 micron of diameter has been manipulated in 3D. Nevertheless these 3D manipulations tend to be hardly reproducible due to the lack of real-time force feedback control and the tip position shifts induced by the open loop displacement stage. Based on this observation and in order to perform efficient manipulations the electronics module of the nano-tweezers has been coupled with a haptic interface to get real-time control of the probe positions and of the strengths applied on objects. A master joystick guides the movement of each slave tip while the frequency shift induced by the tip/sample interaction is directly translated back as a force through the haptic device to the experimentalist.

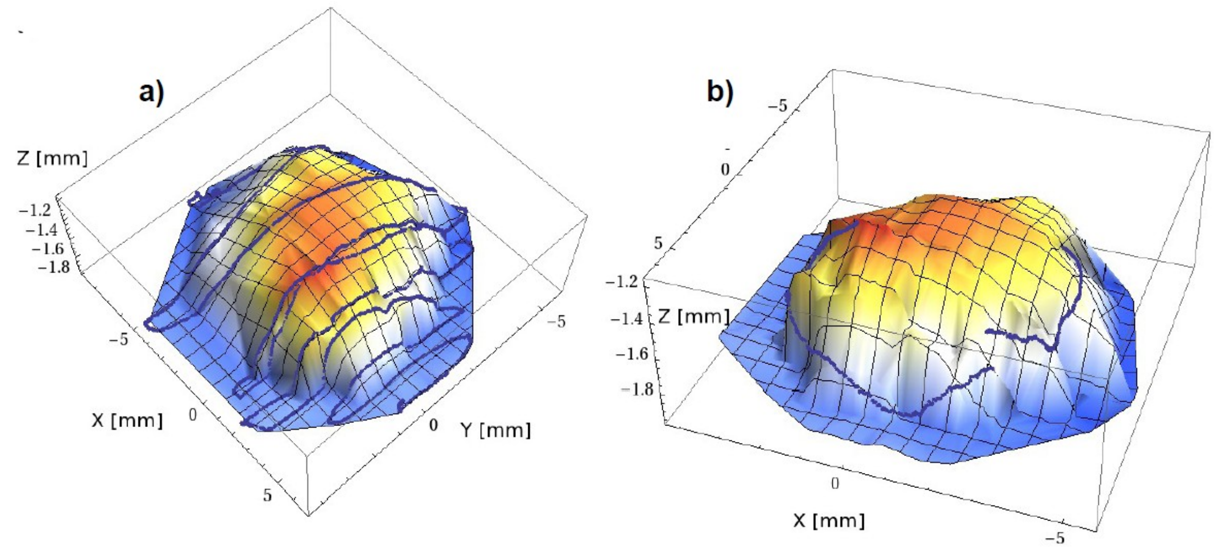
In this configuration, experiments in 1D have been carried out on different kind of surfaces (PDMS membrane, silicon surfaces) to haptically feel and evaluate the perception of elasticity and hardness [5]. In addition a sub-micron sphere of a 400 nm diameter has been haptically localized and reconstructed in 3D in reproducible manner using a force feedback (Figure 2a). Thanks to this haptic interface, the operator can perform complex tasks like following, at constant height, the contour of the 400nm sphere(fig 2b), this task is required to select the gripping points for future 3D manipulation with the two nanofingers.

Figure1



a) Direct teleoperation configuration where the user controls the tip position via the force feedback system. b) System configuration of the nanotweezers. The two nanotweezers fingers and the sample holder are controlled by the same set of devices: Three inertial XYZ motors and a microscanner.

Figure2



Haptic Recognition performed (a) a view of the sample (1mm corresponding to 100nm in real space) topography is obtained following the tip trajectory (blue line) during the user XY scanning. In this case, the user could feel a virtual relief computed via the height of the tip while he is moving in the XY directions. (b) After the sample exploration, the user had to follow the contour of the sphere. His trajectory during the task has been drawn (blue line) over the reconstructed sample view. The scale on the picture refers to the joystick coordinates and belong to the macroscale.

References

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