Low-cost, highly accurate robot for manipulating nanoscale objects

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A new system offers an affordable and versatile alternative for applications requiring actuation and sensing at very small resolution.

Nanotechnology is currently an enormously popular theme in research, not least because modern ‘nanoactuation’ instruments enable imaging, measuring, and manipulating in the nanoresolution range. Major foci of activities and ongoing research include such areas as living cells, carbon nanotubes, functional surfaces, and nanoparticles. These emerging fields require constant enhancement of existing tools to improve resolution and also new ones to target issues that arise only with nanotechnology. Nanoactuation devices currently on the market are very expensive and often limited in their capabilities.

The atomic force microscope (AFM) and its variants are the most common instruments available, and some do provide 3D control. But, because they are based on scanning, they are not well suited for large or nonplanar surfaces or for moving around micron-sized objects such as cells. The high-planarity requirement of AFM also arises in nanolithography, where patterns such as conductors are fabricated on surfaces. We have developed a PC-based robotic system that can be used for several different applications requiring actuation and sensing in nanometer resolution. To make the platform affordable, we use off-the-shelf components.

The concept underpinning our approach is to use a new range of microcontrolled linear-piezo actuator components. These actuators convert small motion into longer movement in a series of repeating steps. We also chose 3D micromanipulation for the specific probe or tip movement rather than conventional scanning. The challenges inherent in our method include inaccurate timing, delays in signal transfer, and a user-interface-dependent central processing unit (CPU) load. This load can be uneven, which causes variations in task length. Moreover, if not optimized, the increased graphical and data content can consume a significant amount of PC power. We overcame these problems through a combination of microcontroller-based external electronics, dual-core computing, and C programming with background tasking.

Our system consists of a haptic user-controlled interface (joystick), a PC, and a piezoelectric actuator (see Figure 1). Both the hardware and control software are based on a generic modular architecture that enables swift changing of the actuators, sensors, and other tools with minimal effort. This makes the system ideally adapted to a variety of uses, of which adhesion patterning and cellular manipulation are just two examples. Testing was done using a real-life case: measuring the friction caused by pushing a small particle on a coated surface.

The main technical features of the system are the following. The haptic 3D controller allows the user to manually direct the robot. The controller has a pen-like handle that provides six

Figure 1. Device platform: probe, actuator, and 3D controller.

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degrees of freedom. The ‘pen’ has two buttons that can be assigned to different functions. The controller also provides a feedback option that enables the user to feel what the robot feels, whether manipulating a particle or simply exploring the surroundings of the probe. The linear-piezo actuator consists of three stages (i.e., mechanical moving axes) with position encoders. In our test case, we used a SmarAct GmbH (Oldenburg, Germany) piezo actuator that can move in a resolution (i.e., the smallest controllable step) of 5nm. The range of each actuator is 3cm.

The system’s versatility is further suited to exploring emerging nanomaterials. All the instruments have a probe or tip that permits submicrometer resolution of the actuator and milliNewton to nanoNewton force sensing. So far, applications have been limited to characterizing adhesion force in biological materials and paper fiber, and mechanical properties such as tensile strength. The probe (measurement head) can be customized to every application separately. In our test case we used a variety of commercial strain-gauge force sensors, as well as a newly developed optical force sensor that is attached to a mechanically custom-designed arm. The probe itself is connected to a voltage amplifier, and also to a 24bit precision analog device converter. A specially designed needle attached to the force sensor feels the surroundings. In some applications, the probe may include an additional device such as a microgripper, which typically is operated by a linear-piezo or bimorph (bending)-piezo actuator. Piezo actuators have high input-voltage requirements (40–300V) that can be controlled by an analog/digital or pulse generator. Their actions normally must be implemented in the control system to compensate probe motion due to the grippers closing.

The main control software runs on a regular PC, using the Windows XP operating system. The software is a hybrid that combines features of function- and behavior-based architectures. Its implementation is very flexible, enabling the system designer to emphasize either deliberative, behavior-based, or reactive features. In the test case we mainly focus on the architecture’s reactive and behavior-based qualities.

Conclusion

For much research at the micro- and nanoscale and for related applications, a low-cost, versatile device platform is a valuable asset. It can be built mostly using off-the-shelf components and with flexible modular software architecture. We have demonstrated our approach in a real-life test case that validates the feasibility of the technology. The platform is being and will be applied to a variety of materials and devices.

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References


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