

## Long Travel Ranges and Accurate Angular Movement Create New Opportunities in Biomedical Manipulation Systems



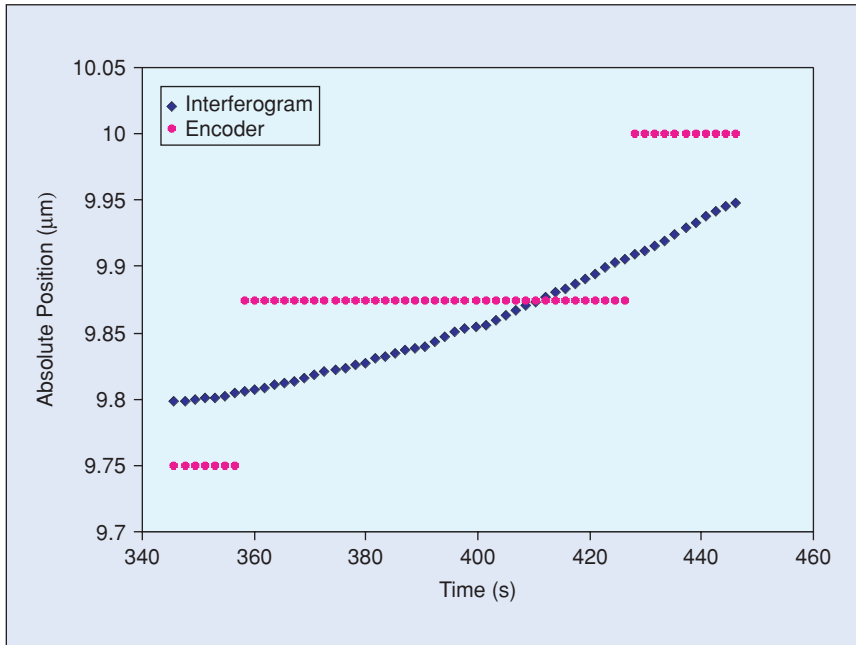
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# AUTOMATED PIEZOELECTRIC NANOPOSITIONING SYSTEMS

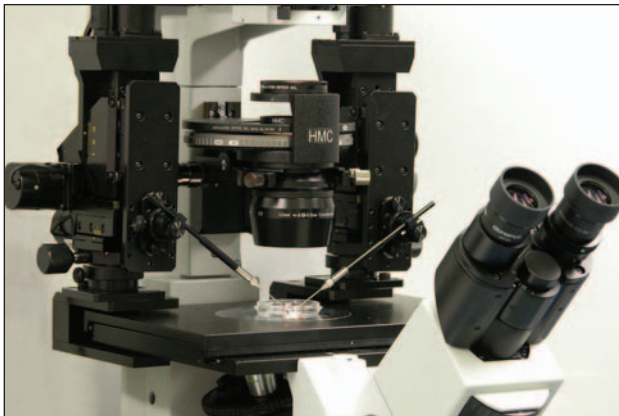
For over 100 years the basic design principle used in standard micropositioner and micromanipulator systems has remained relatively unchanged based on the traditional X, Y and X,Y,Z linear displacement configurations; whereby each axis of linear movement is fixed and perpendicular with respect to an orthogonal axis of linear movement. While a number of technological advances have been made in micropositioner design, such improvements have generally focused on the mechanics and control systems to provide increased accuracy, better resolution, increased stability and reduced drift.

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Despite these improvements it is often desirable during an experimental or manufacturing procedure to alter the angle of approach of a probe/tool with respect to the target sample. Although a number of micropositioner manufacturers have developed ad hoc adapters and devices, or have implemented mechanical design changes that permit movement outside of the orthogonal planes (e.g., rotational movement and/or angular movement of a linear axis); such adaptation is generally cumbersome, requiring the probe/tool to be removed from the target sample while the new position/angle is then pre-set by hand. Until very



1. System evolution during movement of the NTS10-125 linear nanopositioning stage (Discovery Technology International, Florida, USA). Step size 3 nm, velocity—15 nm/s) monitored by laser interferometer. Steps indicate readings of the encoder, every 125 nm. (Data courtesy of Foppe de Haan, University of Groningen)



2. DTI's NM3D-25VP Stem Cell nanomanipulator system mounted on an Olympus IX71 inverted microscope. Picture shows two nanomanipulators mounted on either side of the microscope stage.

recently there is no device commercially available that allowed simultaneous precise control over the angle of approach and linear movement of the probe/tool.

Furthermore, in recent years, an increasing number of biomedical applications have dictated the need for improved positioning resolution of less than one micron (i.e. nanometer) range. Although current linear piezoelectric transducers can achieve nanometer resolution, they suffer from one very important disadvantage—they have a very limited travel range (typically 5–200  $\mu\text{m}$ ). They therefore have limited applications within the field of biomedical research. In the past this limitation has been addressed by designing piggy-back systems, where a piezoelectric transducer having nanometer resolution

is mounted piggy-back style on top of a coarser micropositioners to provide the extended travel range. The performance of such system, measured in terms of design accuracy, resolution and drift, is obviously determined by the coarser mechanical component; in this case the micropositioner. Accordingly, such systems do not provide reliable performance below the micron level.

Linear motorized positioners that rely on the conversion of a rotational movement into linear movement to achieve extended travel range employ traditional dc or stepper motors. Such motors are incapable of very high angular resolution movement and provide translated linear resolution of 0.1  $\mu\text{m}$  or worse, making them inadequate for nanopositioning applications.

In this article we provide information on a new class of nanopositioning systems that are addressing the drawbacks of the traditional technologies and at the same time finding increasing

usage in biomedical research and other applications requiring precise positioning control.

## LINEAR NANOPositionING SYSTEMS

Very recently, a novel piezoelectric rotary motor (PRM) has been described which has shown great promise as an alternative to the traditional dc and stepper motors used in standard linear nanopositioning systems [1]. The PRM combines the benefits of high torque with an unprecedented angular resolution, providing more than 1.2 million increments per single revolution of the motor. This provides for translated linear resolutions of less than 1 nm, making the motor ideal for a variety of nanopositioning applications.

An additional benefit of the new PRM design is that when the motor is de-energized, it operates as a position holder (brake) with practically undetectable backlash and drift (<2 nm at 20°C). Furthermore, the elimination of heat dissipation in the steady-state mode makes the PRM devices ideal in critical applications (e.g., vacuum applications).

The stick/slip is one of the major factors, which limits resolution of nanopositioning systems. The effect is caused by the fact that the coefficient of static friction is greater than the coefficient of dynamic friction. When a driving force is applied to a nanopositioner, movement from rest is slightly delayed on the applied force. Initially, with finite force, there is no movement until the force exceeds the static friction. At this point there is a jump in position. Only frictionless devices such as solid-state actuators (piezo actuators) exhibit zero measurable friction and therefore provide resolution superior to classical mechanical positioners in the submicron to subnanometer range.

However, the PRM based linear nanopositioning systems overcome the stick/slip effect due to the unique start-stop characteristic of the rotary piezoelectric motor. In these systems the angular position of the rotor is locked (held) by the self-decelerating torque of the motor itself. The same force locks the whole friction system of the translation stage. To limit the effect of any jump when initiating motion the unlocking process must occur almost instantaneously (with a time constant in the range of 10–100  $\mu$ s). The PRM has been designed to implement a step formation within 2–10  $\mu$ s/ $\mu$ rad. This timing results in an angular step of the motor in the nano-range, which translates immediately into an equivalent linear step eliminating any static friction effects. Figure 1 illustrates the actual results obtained using a PRM linear nanopositioner measured using a laser interferometer [2].

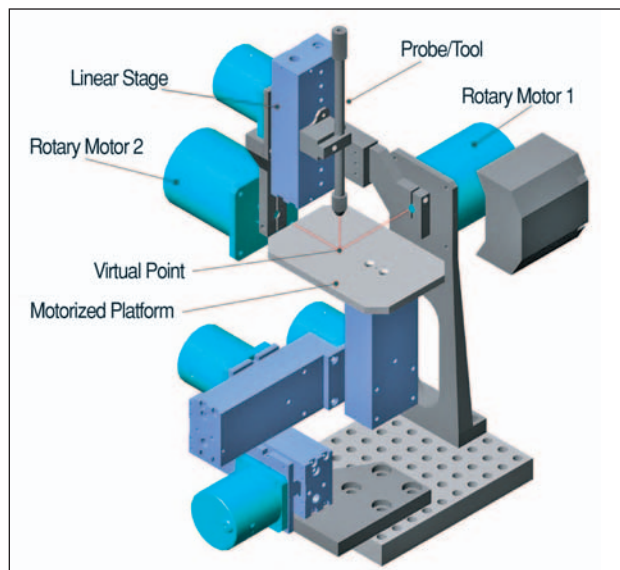
PRM based linear nanopositioning stages can be readily configured into multi-channel systems (e.g., XYZ) to form unique nanomanipulators with unprecedented resolution and accuracy. One such nanomanipulator system has recently been described for use in very demanding biomedical applications, such as stem cell manipulation, in-vitro fertilization and electrophysiology, Figure 2.

### ANGULAR AND ROBOTIC NANOPOSITIONING SYSTEM

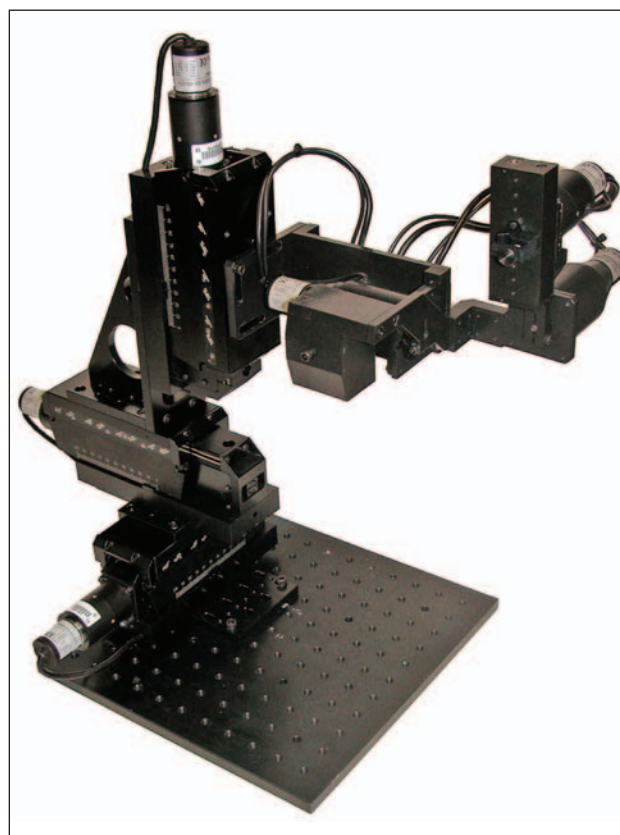
The unique properties of the PRM have enabled novel hybrid motorized nanopositioning systems combining within a single system both linear movement and/or a rotational/angular movement. One such system, the first of its kind to be described, is RoboMate™ (developed by Discovery Technology International, Florida). This system addresses the need for precise motorized angular control in many biomedical applications. Furthermore, the RoboMate system incorporates a novel (patent pending) Virtual Point™ technology that allows the tip of the probe/tool to be positioned accurately to a fixed point on a target sample and remain fixed at that point whilst its angle of approach is continuously varied.

The functional design of RoboMate incorporates two advanced PRMs and a linear stage based on a similar motor technology. Control over angular and linear movement of RoboMate is then achieved using either a joystick or Windows application software. A Virtual Point is formed where the axis of rotation of the first and second rotary motors and the longitudinal axis of the probe/tool intersect, Figure 3. When the tip of the probe/tool is positioned at the Virtual Point, changes in the angle of the probe/tool will not affect the position of the tip of the probe, which will remain at the Virtual Point.

This new system is finding potential uses in several applications, one such application is stereotaxic microsurgery. Stereotaxic devices are used routinely in biomedical research for minimally invasive surgical intervention in tumor surgery [3] and neurosurgery [4], [5]. The traditional method requires the use of published Cartesian coordinates that reference anatomical features of the organ under surgery (e.g., the brain). The simplest stereotaxic instruments incorporate manual (linear and rotational) controls, which enable a probe/tool to be positioned with respect to the target area prior to surgery. Such manual systems



3. Illustration of the functional elements of RoboMate and the concept of the Virtual Point™



4. DTI's NanoRobot-6AX for stereotaxic applications. Enables a tool to be positioned within submicron resolution deep within the brain of a small animal.

have accuracies no better than 500 microns. More advanced devices using motorized stages and/or encoders mounted on to linear stages provide slightly better accuracy to within 10 microns. However, they do not provide the needed motorized integration of both linear and angular coordinates. In these

systems angular movement is provided using *ad hoc* adapters and manual rotational devices, which are generally cumbersome and require the probe/tool to be removed from the target sample while the new position/angle is then pre-set by hand.

To overcome these problems Discovery Technology International developed a novel robotic system for stereotaxic surgery, Figure 4. This new system combines the unique properties of their RoboMate system with an XYZ PRM-based 100 mm travel nanopositioning XYZ system. This configuration enables for the first time precise motorized computer control over all linear and rotational movements.

### SUMMARY AND CONCLUSIONS

A new class of unique linear and angular nanopositioners has been developed based on the novel properties of an advanced rotary piezoelectric motor. These new devices substantially improve positioning performance and open new possibilities for biomedical research studies.

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