3D Force Microscope

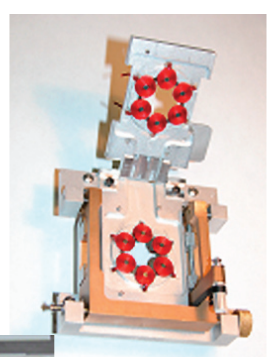
Department of Computer Science University of North Carolina at Chapel Hill February 2005

Although the use of magnetic technologies in biology dates to 1949, they have been applied by relatively few groups in basic biological or biomedical research. Technologies for precision studies of forces in biological systems include Atomic Force Microscopy, optical tweezers, MicroElectroMechanical Systems (MEMS), and magnetic forces. Magnetics has the benefits of combining a freely moving probe, as in laser tweezers, with the relatively high forces of an AFM—without damaging the sample. The goal is a 3D Force Microscope (3DFM) with a magnetic bead probe that can be pulled in any direction under user control with the position of the bead tracked dynamically at the nanometer scale. The 3DFM will be able to be used on single molecules, in cells and cell cultures, and in biomaterial studies.

The Challenge

Developing the 3DFM presents challenges in magnetics design, in making the mechanical system suitable for use with high numerical aperture commercial light microscopes, the tracking and control systems, and the user interface.

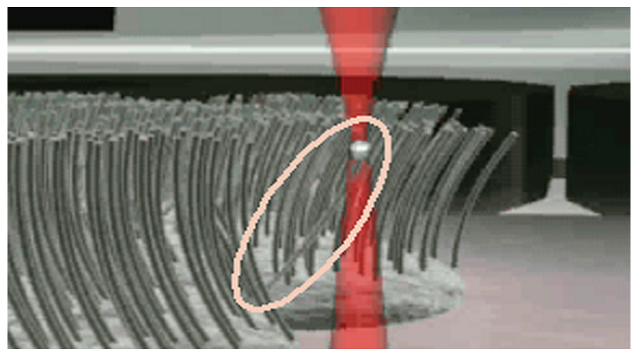
The goal has been to be able to apply forces in any arbitrary 3D direction. Our novel hexapole design meets this criterion and its geometry allows the pole plates to be microfabricated from permalloy materials onto the specimen cover slips. In use, the pole plate cover slips are positioned between the upper and lower coils visible in the open stage assembly. They are easily removable and so the magnetic field geometery can be redesigned and changed at will.



Objective visible in center image

Highlights

- **Magnetic beads apply forces to probe biological systems in 3D**
- **Nanometer tracking combined with nanoNewton forces**



Simulated view of magnetic bead attached to a cilium being pulled by 3DFM

Designing the control system for the 3D force microscope is major activity of this project. Critical areas are tracking the bead with high accuracy, controlling the motion of the stage based on bead position, and calibrating the instrument in real time. High spatial resolution and high bandwidth tracking is achieved with a combination of coarse video tracking and fine-level tracking with a laser trap. Finally, the control system manages the magnetics, including control of the current levels that generate forces and calibration for the particular pole geometries of an experiment.

The bead position/ displacement provides information on the bead's environment. This data is measured in real time and is displayed through the user interface to help the user guide the experiment. The user interface provides a haptic-feedback device so that the user has a sense of actually tugging on the bead to move it through the specimen. As the bead's motion is within a 3D volume, the visualizations are of necessity in 3D. Among the views that the user can choose are a trace of the bead in 3D, the volume swept by the bead, the image from the video camera (part of the video tracking system), and a vector representing current force direction.

Use with force-feedback interface to 3DFM.

Project Leaders

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Research Sponsors

Current Sponsorship
NIH National Institute for Biomedical Imaging and Bioengineering (NIH P41EB 002025-22, R01-EB00761)
Past Sponsorship
NIH National Center for Research Resources (NIH P41 RR 02170)

Selected presentations of this work

Superfine , R. (Dec. 1-5, 2003). "Nanomachines and Manipulation in Live Cell Cultures," Materials Research Society Fall Meeting, Boston, MA.

Fisher, J., R. Superfine , T. O'Brien, R. M. Taylor II, C. W. Davis, H. Matsui, L. Vicci, G. Matthews and B. Wilde (March 1-5, 2003). "Motion and Force Generation of Cilia in Human Lung Cell Cultures," 47th Annual Meeting of the Biophysical Society, San Antonio, TX.

Fisher, J. (Nov. 6-8, 2003). "3D laser tracking of a particle in 3DFM," 70th Annual SESAPS, Wilmington, NC.

Superfine , R., L. Vicci, J. Hao, J. Fisher, B. Wilde, R. M. Taylor II and T. O'Brien (Oct. 1-4, 2003). "Microfabricated Magnetic Pole Structures for Biological Force Measurements," Biomedical Engineering Society Annual Conference, Nashville, TN.

Fisher, J., B. Wilde, T. O'Brien, J. Cribb, L. Vicci, R. M. Taylor II and R. Superfine (Oct. 1-4, 2003). "Motion and Force Generation of Cilia in Human Lung Cell Cultures," Biomedical Engineering Society Annual Conference, Nashville,TN.

Wilde, B. (Nov. 6-8, 2003). "Manipulating Cilia Using the 3DFM," 70th Annual SESAPS, Wilmington, NC.

Superfine , R. (June 15-18, 2003). "Touching at the Nanoscale: Particle Properties in Devices and as Microprobes," 77th American Chemical Society Colloid and Surface Science Symposium, Georgia Tech University, Atlanta, GA.

Superfine , R., M. Falvo, S. Washburn, R. M. Taylor II, L. Vicci and C. W. Davis (Oct. 13-14, 2003). "NEMS: Tools, Nanostructures and Biology," 3rd Swiss/US-Nanoforum, University of Basel.

Wilde, B. (April 25, 2003). "The Three Dimensional Force Microscope: The Instrument and It's Applications," 4th Annual Celebration of Undergraduate Research at UNC-CH, Chapel Hill, NC.

Carroll, R. L., B. Wilde, S. Washburn and R. Superfine (Fall 2003). "Three-Dimensional Imaging of Magnetic Fields," Materials Research Society Fall Meeting, Boston, MA.

Padmanabhan, S. B., R. L. Carroll, R. E. Cheney, S. Washburn and R. Superfine (March 1-5, 2003). "Controlling Actin Motion on Myosin Surface in Microfluidic Channels." 47th Annual Meeting of the Biophysical Society, San Antonio, TX. Published in: Biophysical Journal (Annual Meeting Abstracts).

Key Words

Force microscopy, forces in biology, magnetics

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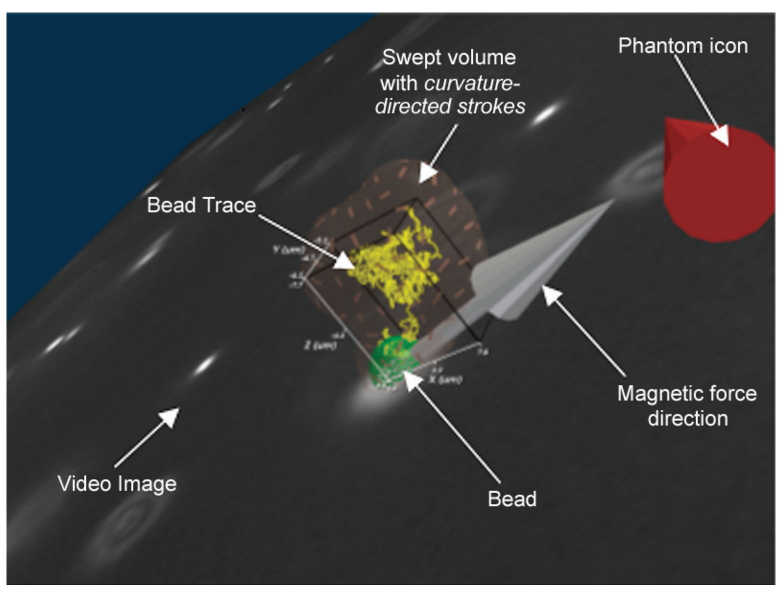

Variety of visualizations the user can opt to see.