Micro Flow Control Particle Tweezers

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We show how to steer many particles at once in a micro fluidic chamber by generating the correct time-varying flow fields using electroosmotic actuation. The basic idea is shown in Figure 1: we fabricate a planar micro fluidic device with an array of electrodes which create electric fields that can move the flow by electroosmotic forces [1]; the resulting motion of neutral or charged particles in the chamber is observed by a vision system (the size of this system can be miniaturized); a controller compares the observed motion to the desired motion and computes new electrode inputs to create the right flow field at the next instant in time; this control feedback loop repeats and the end result is that all the particles are steered along their desired trajectories. Using this method, we can replicate the capability of laser tweezers using cheap, electrically actuated micro fluidic devices, a micro camera (such as the ones found in cell phones), and some control algorithms. No lasers are needed. Charged particles are actuated directly by the electric field; neutral particles are carried by the flow that is created by the electroosmotic forces. When completed, our entire system will be handheld and will cost in the range of hundreds of dollars (the miniature camera is the most expensive part).

This idea of using temporally and spatially varying flow fields to steer particles is only possible on the micro scale. The equations that describe low Reynolds (Stokes) flow are sufficiently simple that we can answer the required inverse question: given a desired spatially complex flow, find the actuator inputs that will create this flow field. (At high Reynolds numbers, nonlinear fluid effects and turbulence make it impossible to solve/implement such an inverse problem.) We solve the inverse problem in real time using the method of least squares and singular value decomposition [2] is used to precondition the least squares problem. The solution of the inverse problem provides the electrode voltages that must be applied given the current position of the particles. Particle positions are established by a camera and a vision processing algorithm in real time. The feedback loop of actuate, sense, and correct is continually adjusting for noise and experimental variations to keep all the particles on track.

To date we have demonstrated the steering of a single yeast cell experimentally, and the steering of many particles at once in simulation (see Figure 2). Current simulations contain a realistic amount of actuator and sensor noise that we see in the experiments. Our next step is to experimentally steer many yeast cells at once. We have submitted a patent on this micro flow control particle tweezer invention, and this invention has been nominated for the best patent of the year award at the University of Maryland.

References:

1. Probstein, R.F., *Physicochemical Hydrodynamics: An Introduction*. 2 ed. 1994, New York: John Wiley and Sons, Inc.
2. Strang, G., *Linear Algebra and its Applications*. 3 ed. 1988, New York NY: Saunders College Publishing.

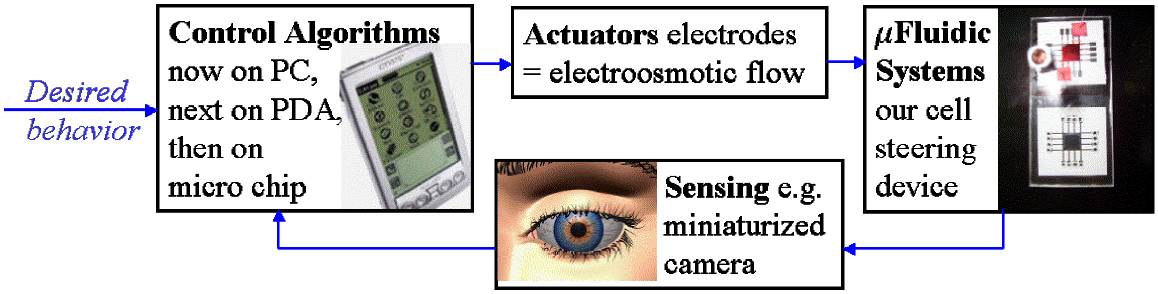

Figure 1: The flow control feedback loop. Starting from the left: The desired behavior is the required trajectories for all the particles (e.g. cells); the control algorithm compares the actual position of the particles to the desired position, it computes a set of actuator voltages that will move the particles from where they are to where they ought to be; the electrode actuators apply these voltages; an electric field and fluid flow is created inside the micro fluidic device, both neutral and charged particles move accordingly; the miniature camera and vision algorithm identifies the new position of the particles, it reports their position to the controller; the sense-compute-actuate loop now repeats.

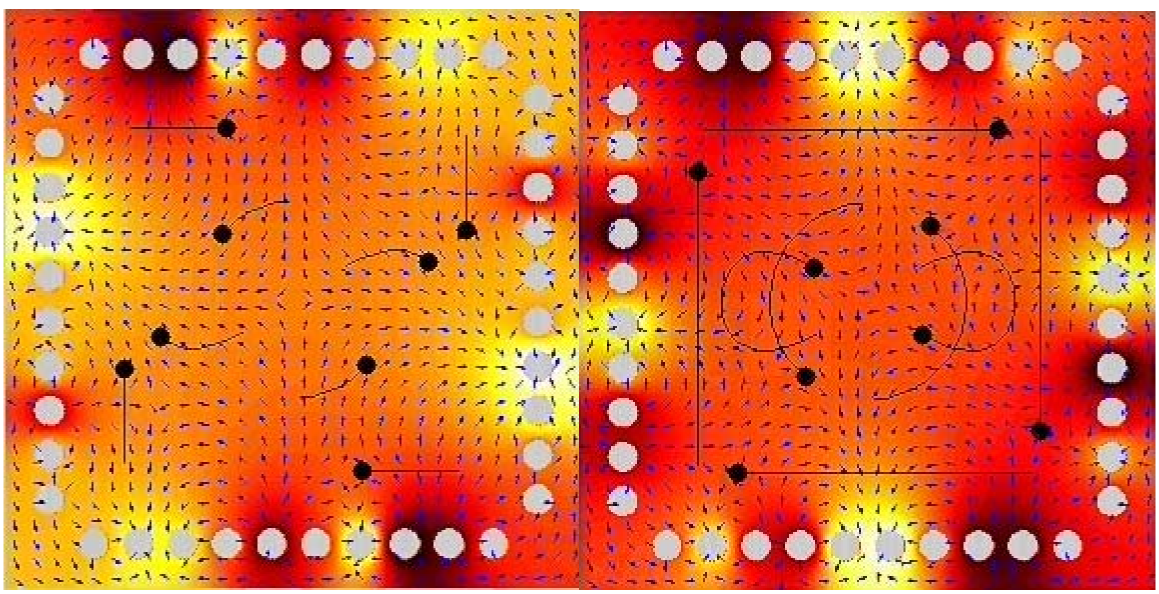

Figure 2: Multi-particle steering by electroosmotic fluid actuation and control. The view is from above, and two time instants are shown. Large grey circles are the actuating electrodes; small black circles are the four neutral particles to be controlled; the color field corresponds to the instantaneous voltage field φ(x,y): black/red corresponds to a high voltage, white/yellow corresponds to a low voltage; and the blue vectors are the resulting fluid velocities which are along the electric field due to electroosmotic and viscous forces. The four particles execute the motion shown by the black curves.