Magnetic Micro-transporters: Applications in Bioengineering

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The application of targeted directed forces to individual microscopic objects or biological entities in near-native environments is central to numerous emerging opportunities in engineering and medical research. The need for control over the relevant forces in these situations has become even more important since the functionality of micro- and nano-electromechanical systems (MEMS, NEMS) continues to become more complex. Driven in part by these needs, development of micro-manipulation techniques has witnessed many successes. For instance, the ability of light and oscillating electric fields (optical tweezers) to grasp and move micro-scale objects in a non-contact manner and the technique of dielectrophoresis where an electric field results in a force on a charged or polarizable neutral unit, have enabled selective spatial manipulation of tiny objects. Likewise, conventional magnetic tweezers have evolved into a useful tool in soft condensed matter and biological physics. They have been used to study transport of ferrofluids, to stretch and manipulate DNA, and to probe protein networks in the cell environment.

In advancing techniques that provide pico- to femto-Newton scale forces at the micro- and nano-scale several challenges must often be addressed. These challenges arise from: (a) the need for non-contact manipulation, (b) the necessity, especially with diminishing object size, for large localized optical fields, or electrical/magnetic fields with high gradients that do not adversely affect the targeted object, (c) stochastic forces such as those arising from Brownian fluctuations that hinder directed movement, (d) parallel manipulation for improved throughput and (e) selectiveness to maneuver objects with desired characteristics across different surfaces.

We have developed new approaches, based on programmable magnetic signatures patterned on a surface, to create microscopic transporters whose trajectories and functionalities are remotely controlled. Requiring only five tiny electromagnets, a game controller to direct the motion and the power equivalent to a 60W light bulb, tunable femto- to pico-Newton range forces guide, assemble and manipulate magnetic nano-particles, as well as labeled and unlabeled biological cells in a fluid environment.

Highlights of these joystick- and voice-activated approaches for fundamental nanoscience, engineering, biomagnetics and medicine will be discussed as we move towards realizing new micro- /nano-scale devices and intra-cellular probes.