Focused issue on micro-/nano-robotics

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Micro-/nano-robotics research applies principles and knowledge from the broader robotics field to applications characterized by interaction with the external world at size scales of microns to nanometers. Micro- or nano-robotic systems may themselves be miniature in size, or they may be designed specifically to interact with micro- or nano-sized structures. The ability to interact in automated or semi-automated fashion with the environment at such scales generates unique new opportunities for scientific study, medical diagnosis and treatment, precision manufacturing, and exploration, among other applications. This focused section on micro-/nano-robotics presents eight ongoing research activities in the miniature robotics area.

Arguably the most prominent motivation for micro-/nano-robotic research is to enable new interactions with biological organisms, whether for purposes of basic research or to generate new avenues for diagnosis and treatment of disease. “Passive-Active Hybrid Release Strategy for Micro-object Separation”, by Crimp, Suhaimi, and Avci, demonstrates a robotic system to rapidly pick-and-place microbeads, as a step toward oocyst manipulation for biomedical studies and precision medicine. This requires a close examination of adhesion force effects on micro-manipulator and cell/object interaction, to ensure that objects can be held and then released by manipulators at desired locations.

A companion paper, “Auto-focusing Approach on Multiple Micro Objects using the Prewitt Operator”, by Lofroth and Avci, is intended to further improve speed of micro-manipulation tasks by increasing the efficiency with which

micro objects may be identified and made the center of the focal plane when using optical imaging for feedback and tracking. This is especially important when the objects to be tracked are motile biological specimens that may move in and out of the focal plane.

Beyond physical contact or perturbation, optical and thermal manipulation techniques provide avenues for designing, altering, or assembling nano-scale systems. “Nano-assembly and Welding of Gold Nanorods based on DNA Origami and Plasmon-induced Laser Irradiation”, by Liu, Liu, and Shen, introduces a method for using DNA templates to induce rotation and positioning of gold nanorods to ensure that laser welding will bond the nanorods in desired orientations. The technique has potential to produce new material architectures and micro-robotic assemblies.

Yet another approach to manipulation and locomotion at the nano-scale is electromagnetic coupling, especially in a fluid, whether to propel nano-robots or sort and position micro objects. “Pairwise Controllability and Motion Primitives for Micro-Rotors in a Bounded Stokes Flow”, by Buzhardt, Fedonyuk, and Tallapragada, examines the fundamental theoretical interaction between microswimmers modeled as rotlets in low Reynolds number flow, to show that combinations of multiple rotlets may produce motions that would be impossible for an individual, and that these motions are controllable in a bounded domain.

Small-scale manipulation can also be bridged between biomedical and nano-manufacturing and metrology applications, whenever circumstances requires extremely high accuracy (nanometer-level) precision in object positions. Real-time Motion Planning of Multiple Nanowires in Fluid Suspension under Electric-Field Actuation by Yi, Yu, and Shan addresses scalability of nano-manipulation procedures to rapid positioning of multiple nanostructures, using efficient search algorithms while dealing with many of the complex small-scale fluid–structure interactions encountered when manipulating biological specimens.

Nanometer level positioning is likewise a critical issue in metrology applications such as atomic force microscopy and transmission electron microscopy. A robotic platform

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or stage for performing sample positioning in such settings could improve flexibility, speed, and range for precision imaging and assembly. “A 3D-Printed 3-DOF Tripedal Micro robotic Platform for Unconstrained and Omnidirectional Sample Positioning”, by Adibnazari, Nagel, and Leang, demonstrates that a low-cost, rapid-prototyped micro-robot for this setting can begin to harness these benefits while maintaining high-accuracy positioning.

Returning to the theme of biomedical applications, micro-positioning apparatus have also been developed for use in medical procedures, and “A Large Air Gap Magnetic Levitator for Intra-Arterial Positioning of a Clinical Microcatheter: Modeling and Control”, by Zaccardo, Miller, and Buckner, examines how electromagnetic levitation might be utilized for precise catheter insertion. Such catheters are used, for example, in delivery of radioactive microspheres for cancer targeting, and improved positioning may enhance efficacy and reduce unwanted tissue damage of cancer treatment.

Finally, research to produce fully autonomous micro-robots also continues in a number of laboratories around the world. “Design and Analysis of Varied Gaits in Elastic Vibratory Milli-Robots”, uses a rapid-prototyped centimeter-scale testbed to explore one approach to dynamically expanding mobility of robots based on micro electromechanical system (MEMS) fabrication processes, in which motion is primarily dependent on elastic deformation of appendages and mechanisms.

Together, we believe the above articles provide a useful survey of developments in the field of micro- and nanorobotics, addressing issues of small-scale manipulation, measurement, planning, assembly, locomotion, and control. We thank the editor-in-chief and staff of the International Journal of Intelligent Robotics and Applications for this opportunity to focus on activity in the field, and hope that readers will find much value in this issue.

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