Micro- and Nanoscale Robotics

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For the miniaturization of devices and machines down to atomic and molecular sizes, micro/nanorobotic approach enabling precision manipulation, manufacturing, and interaction at the micro- and nanoscales is indispensable. Micro/Nanorobotics as an emerging field is based on the micro/nanoscale physics, fabrication, sensing, actuation, system integration, and control taking the scaling effects into consideration. Micro/Nanorobotics encompasses: (i) design and fabrication of micro/nanorobots with overall dimensions at the millimeter and micrometer ranges and made of micro/nanoscopic components; (ii) programming and coordination of large numbers of micro/nanorobots; and (iii) programmable assembly of micro/nanoscale components. This tutorial will focus on state-of-the-art micro/nanorobotics research topics, challenges, and activities around the world and at the NanoRobotics Laboratory.

As the first focus area, precision nanomanipulation systems using Atomic Force Microscope (AFM) probes will be introduced. Here, AFM probes are utilized as a pushing, pulling, cutting, and indenting type of nanomanipulator, and also as a three-dimensional (3-D) topography and force sensor. As the first application, using an AFM probe and a teleoperated human-machine interface, fine gold particles down to 14nm radius are positioned in two-dimension by mechanical pushing for developing micro/nanoassembly technology, and teleoperated touch feedback from the surfaces at the nanoscale is realized. Next, liquid polymers are pulled and solidified precisely by an AFM probe to manufacture customized 3-D polymer micro/nanofibers. Next, design methodology, analysis, and fabrication of biomimetic fibrillar adhesives inspired by geckos are explained. Geckos have unique dry adhesive fibers in their feet to climb any surface with a very high maneuverability. Discovering the principles of gecko adhesion recently, synthetic polymer micro/nanofibers are fabricated using micro/nanomolding techniques. The results of current prototype adhesive fibers and miniature climbing robots inspired by geckos are reported. Finally, miniaturization issues of micro/nanorobots are discussed. As current miniature robotics activities, biomedical swimming and endoscopic capsule microrobots, water strider robots walking on water, and Integrated Nano-Tool Carrier walking robots are explained briefly, and challenging issues are addressed. These miniature robots could revolutionize health-care, environmental monitoring, manufacturing, and space exploration applications in the future.