Guest Editorial: Focused Section on Nano/Micromotion System: Design, Sensing, and Control

I. Introduction

NANO/MICROMOTION systems (NMMS) have become the enabling tool in a broad spectrum of fields, ranging from nanosciences and nanotechnologies to advanced manufacturing and robotics [items 1)–4) in the Appendix]. By using NMMS, a wide variety of subjects can now be precisely measured, manipulated, synthesized, and fabricated at unprecedented small scale and high resolution [items 2), 5), and 6) in the Appendix]. Central to achieving these functions and performance are the advances in the design, sensing, and control of NMMS [items 7)–9) in the Appendix]. Challenges, however, are presented to meet the continuously increasing demands in emerging applications at nano/microscale. For example, direct/embedded high-precision sensing and actuation under physical constraints and noise effect is required in accurate micro/nanoscale manipulations [item 10) in the Appendix], and multi-degree-of-freedom (DOF) positioning and motion control under dynamics–hysteresis effects and nonlinear dynamics is needed in high-speed atomic force microscope (AFM) [item 11) in the Appendix]. These challenges have been attracting interests from the researchers around the world.

This Focused Section assembles a series of latest work contributing to the design, sensing, and control of NMMS. Both hardware innovations and methodology developments are covered, balancing theoretical analysis and modeling with experimental demonstration and discussion.

II. Highlights of the Focused Section

Sixteen articles are featured in this Focused Section, addressing issues ranging from mechanical design of microrobots and precision devices, to advanced control methodologies for a diverse applications, including medical science, microrobotics, atomic force microscopy, biomedical engineering, and vehicle disturbance rejection.

Precision actuation mechanisms are central to all sensing and manipulation operations at micro- and nanoscale [item 9) in the Appendix]. The continuously increasing demands in various applications pose new challenges to the design of mechanism and actuation systems [items 12) and 13) in the Appendix]. For example, one of the long-standing challenges is to achieve, simultaneously, large stroke (displacement range), high-mechanical bandwidth (natural frequency), and large force output, while maintaining a compact mechanical structure and nanoscale spatial resolution [items 8) and 9) in the Appendix]. Especially, design of compact NMMS for rotatory motion has been hurdled by often needed complicated mechanical structure with large self-size.

Four articles in this Focused Section provide their very recent approaches to tackle the aforementioned challenges. Specifically, both H. Yu *et al*. and X. Yang *et al*. aimed to create mechanisms to alleviate the tradeoff between stroke and dynamics bandwidth, with two distinct designs. H. Yu *et al*. proposed a simple, ring-structure of piezo stacks to generate rotary motions. The device is compact, easy to assemble, and has good extendibility and high bandwidth. Interestingly, X. Yang *et al*. explored a piled-up structure using hexagonal flexure beams units to attain both large stroke and high natural frequency. In the multi-DOF domain, S. Kang *et al*. developed a six-DOF direct-driven flexure stage in a fully parallel configuration to gain the benefits of high load capacity, high bandwidth, and low cost.

Microrobot systems, when operated in network configuration, require an effective nontethered power transmission and locomotion system [item 14) in the Appendix]. Although electromagnetic systems are promising to alleviate this issue, the globally applied magnetic field (to all microrobots) limits the manipulation to uniform control of the entire group all together only [item 1) in the Appendix]. B. Johnson *et al*. explored a design based on localized magnetic field system using microcopies in a multilayer printed circuit board (PCB) to achieve independent control of microrobots in arbitrary planar directions.

Another area where NMMS play a central role is the AFM, one of the most important tools in nanoscience and nanoengineering. In over a decade, great attentions have been attracted to both hardware innovations and control of AFM. Recent research in AFM has being focused on high-speed imaging [items 11) and 15) in the Appendix], aiming to enable interrogation of dynamic processes at nanoscale, for example, live cellular and subcellular activities at single cell and molecule level. Challenges in high-speed AFM operation, however, arise from the adverse effects of the dynamics and hysteresis of the AFM scanner and the stiff nonlinear force-distance relation of the probe-sample interaction. Moreover, the imaging speed is also limited by the raster scanning of the probe during AFM imaging [item 11) in the Appendix].

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The five AFM-related articles in this Focused Section approached high-speed AFM from three different angles. Y. Wu *et al*. and L. Li *et al*. proposed to improve the scanning speed of AFM by optimizing the scanning trajectory via statistics analysis techniques, or exploiting fractional repetitive control implemented via a data-driven approach based on finite impulse response, respectively. To enlarge the scanning range of AFM, D. Guo *et al*. combined spatial-temporal trajectory design with dual-stage configuration of nanopositioning system. Alternatively, to improve the imaging efficiency of AFM, Baker *et al*. presented a piecewise undersampling method based on the compressed sensing theory to reduce the imaging area. At last, J. Wang and Q. Zou addressed the issue of rapid probe engagement and withdrawal, by proposing a learning-based online-searching approach to account for the stiff nonlinear probe-sample interaction dynamics.

Control also appears as a crucial issue in a broad range of NMMS applications [items 3) and 6) in the Appendix]. High-speed positioning in multiple coupled directions with stringent positioning accuracy remains one of the key research topics, due to, predominantly, the time varying behaviors of the systems that are sensitive to perturbations. Modeling the behavior of micro- and nanoscale devices appears to be complicated, and complicated tradeoffs exist between the computational cost and the targeted performance. Control based on imperfect model and weak feedback remains as an open research topic.

To tackle the above control challenges, seven articles provided complementary approaches, focusing on obtaining high quality measurement feedback signal or developing control strategies based on advanced modeling. Y. Tan *et al*. proposed an online optimization of positioning control, along with modeling error compensation for exhaust gas recirculation valve system. J. Lee combined the super-twisting algorithm with time-delay estimation technique to develop robust precision control for transoral laser microsurgery application. H. Bettahar *et al.* presented a photo-robotic approach to achieve automated, six-DOF and nanometric positioning of optical system. S. Mashrafi *et al.* offered a robust control strategy of a 3-DOF piezo-actuated flexure stage for X-ray microscopy. J. Wu *et al*. explored the use of electric field-based approach to manipulate multiple nanowires independently via online estimation and motion planning. The equally important state estimation and identification issue has also been investigated. Y. Fan *et al.* presented an integrated disturbance estimation/compensation technique for gyroscope sensors of submilliradian precision, to reject broadband vehicle disturbance, and Y. Chen *et al*. developed a nonlinear motion estimation technique based on parametric resonant dynamics for endomicroscopy applications.

Design, sensing, and control at nano/microscale continuously contributes to the expansion of our exploration in frontier science and technology, thereby, ultimately to the benefits of human being and society. It is our hope that this Focused Section will inspire the readers to advance this excitation area further into the future.

Acknowledgment

The Guest Editors would like to sincerely thank all the contributors who submitted their manuscripts to this Focused Section. They are grateful to the past and current Editor-in-Chief and their office for supporting the overall effort of bringing these technical contributions to the readers, and would also like to thank the all reviewers for their critical but constructive comments.

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Appendix
Related Work

1) X. Yan *et al.*, "Multifunctional biohybrid magnetite microrobots for imaging-guided therapy," *Sci. Robot.*, vol. 2, no. 12, Nov. 22, 2017, doi: 10.1126/scirobotics.aaq1155.
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3) F. Peng, Y. Tu, and D. A. Wilson, "Micro/nanomotors towards in vivo application: Cell, tissue and biofluid," *Chem. Soc. Rev.*, vol. 46, no. 17, pp. 5289–5310, 2017.
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8) A. J. Fleming and Y. K. Yong, “An ultrathin monolithic XY nanopositioning stage constructed from a single sheet of piezoelectric material,” *IEEE/ASME Trans. Mechatronics*, vol. 22, no. 6, pp. 2611–2618, Dec. 2017.
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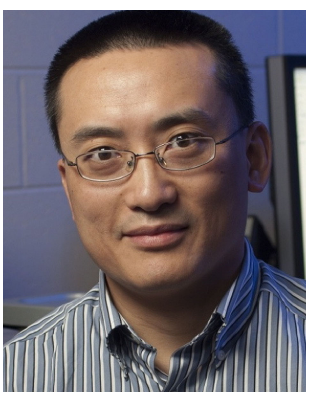
15) T. Ando, “High-speed AFM imaging,” *Current Opinion Structural Biol.*, vol. 28, pp. 63–68, 2014.



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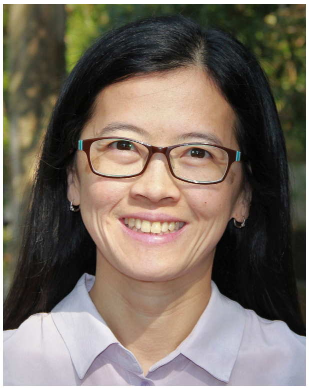

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