Experiments and Simulations of Autonomous Microscale Robotics

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Technical Summary:

Sub-millimeter microscale machines capable of navigating inaccessible spaces and remote locations are steadily approaching reality, with a rich literature emerging on externally actuated and supervised agents. In comparison, progress is slow towards autonomous, intelligent microscale agents able to perform tasks independently. This thesis builds towards fundamental aspects of the field, tackling unanswered questions in robotic functionalities, fabrication techniques, applications, and control. Specifically, (i) I expanded upon the cleanroom-free autoperforation technology to allow facile metal patterning on 2D material surfaces, with which I fabricated mobile electronic microparticles; (ii) Based on experimental observations of autoperforated micro-architectures, I introduced an electrical circuit which integrates real-time access to memory, sensing, and actuation with significantly reduced design complexity as well as compatibility to additive technologies and materials; (iii) I built an in silico modeling toolbox which predicts the performance of a user-defined glucose-responsive insulin (GRI) in animals and humans. I demonstrated the model's applicability to aiding the design of microrobotic delivery and monitoring systems circulating in the human body, as well as to the investigation of the unsuccessful clinical translation of a unimolecular GRI; (iv) Lastly, I explored the collective intelligence in the form of emergent self-oscillation, among a group of simple, unassuming microparticles. I studied the counter-intuitive order arising from intentional breakage of the collective's symmetry, and harnessed the stable periodic mechanical motion for the generation of oscillatory electrical currents as well as cyclically driving microrobotic loads. These advances pave the way towards microscale machine intelligence – either through on-board integration of functionalities or through collective behavior – which enables sophisticated microrobotic tasks without external supervision or manipulation.

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