The 1966 movie *Fantastic Voyage* captured the world’s imagination, portraying a tiny submarine navigating through the human bloodstream and treating life-threatening medical conditions. In the real world, micro/nano-scale propulsion in fluids is quite challenging due to the absence of inertial forces. My research focuses on developing synthetic nano/micromotors capable of converting energy into movement and forces which can address this problem and help to realize the *Fantastic Voyage* vision of delivering therapeutic and diagnostic agents to previously inaccessible areas of the body.

**Highly Efficient Catalytic Microengines.** Although micro/nanomotors can be propelled by different mechanisms, catalytic tubular microengines are particularly attractive for practical applications due to their efficient bubble-induced propulsion in relevant biological fluids. While they offer attractive performance, their practical utility is greatly hindered by the complexity of cleanroom fabrication process and limited materials diversities. To address these issues, I developed a new highly efficient polymer-based tubular microengine which can be prepared using a greatly simplified template electrodeposition method (Figure 1). Such microengines consist of different polymeric outer layers and of various inner catalytic surfaces. These oxygen-bubble-propelled micromotors can operate in low levels of \( \text{H}_2\text{O}_2 \) fuel (down to 0.2%) with a record-breaking speed of 1400 body lengths/s. The attractive propulsion performance and precise motion control of synthetic micromotors hold considerable promise for diverse practical applications.

**Micromotors for Bioisolation.** Bioisolation represents a major challenge because of the complex composition of biological samples. We have successfully added different functionalities onto micromotors for efficient isolation of diverse biotargets (e.g. cancer cells, DNA, protein and bacteria) from fuel-enhanced biological...
environments. For example, lectin-modified PANI/Pt microengines are used for selective bacteria (E. Coli) isolation from food, clinical and environmental samples (Figure 2a); PAPBA/Ni/Pt microengine is presented for glucose and yeast cell isolation based on a “built-in” recognition capability (selective monosaccharide recognition of boronic acid-based outer layer).

**Micromotors for Environmental Applications.** The advances in synthetic micro/nanomotors have opened new horizons for addressing environmental problems. For example, we introduced a novel strategy for in situ water-quality testing based on changes in the propulsion behavior and lifetime of biocatalytic PEDOT/Au-catalase microfish in presence of aquatic pollutants (e.g., heavy metals, pesticides); alkanethiols modified PANI/Pt microengines are used for cleaning oil-contaminated water samples through interaction between hydrophobic outer layer and oil droplets (Figure 2b).

**Nanomotor Lithography.** The complexity and high cost of the state-of-the-art high-resolution lithographic systems are prompting unconventional routes for nanoscale patterning. We have developed a fascinating nano-patterning approach, named ‘nanomotor lithography’, which translates the autonomous movement trajectories of nano/micromotors into controlled surface features. As a proof of principle, we use metallic nanowire motors as mobile nanomasks (to produce ridge lines) and Janus sphere motors as near-field nanolenses (to produce trench lines) to manipulate light beams for generating a myriad of nanoscale features through modular nanomotor design.

*Figure 2.* a) Lectin modified microengines for bacteria isolation. b) Alkanethiols modified micromotors for oil cleaning.

*Figure 3.* Nanomotor lithography by using a nanowire motor as a self-propelled nanomask (a-c) and a Janus motor as a self-propelled nanolens (d-f).
Complex spatially defined nanofeatures using these dynamic nanoscale optical elements can be achieved through organized assembly and remote guidance of multiple nanomotors. We can also use mechanical, electrical, and chemical effects for nanomotor lithography by incorporating specific functionality into the nanomotor. For example, glucose oxidase modified nanomotors can be used for patterning 3D microhelices. Such ability to transform predetermined paths of moving nanomachines to defined surface patterns provides a unique nanofabrication platform for creating diverse nanodevices.

**Toward In Vivo Use of Micro/Nanomotors.** The requirement of non-biocompatible chemical fuels greatly hinders many practical applications of common chemically-propelled nanomotors, especially biomedical ones. To overcome this major barrier, I developed new biocompatible and biodegradable micromotors which can be self-propelled in natural environments: PANi/Zn microrockets display effective autonomous motion in extremely acidic environments (such as gastric acid); Al-Ga/Ti Janus micromotor can be self-propelled by the hydrogen bubbles generated from the rapid aluminum and water reaction; seawater-driven Mg Janus micromotors, which utilize macrogalvanic corrosion and chloride pitting corrosion processes, can be used for environmental oil remediation. In the latest study, we reported the first in vivo study of synthetic micromotors in a living organism using a mouse model. Such in vivo evaluation examines the distribution, retention, cargo delivery, and acute toxicity profile of synthetic PEDOT/Zn motors in mouse stomach via oral administration. We demonstrate that the acid-driven propulsion in the stomach effectively enhances the binding and retention of the motors as well as of cargo payloads on the stomach wall. The body of the motors gradually dissolves in the gastric acid, autonomously releasing their carried payloads, leaving nothing

![Figure 4. The first in vivo study of synthetic micromotors: schematic (a), retention (b) and toxicity (c) of the zinc-based biodegradable micromotors in the mice stomach.](image)
toxic behind. These works are anticipated to significantly advance the emerging field of nano/micromotors and to open the door to in vivo evaluation and clinical applications of these synthetic motors.

**Bioinspired Magnetic Nanoswimmers for Drug Delivery.** Magnetically-propelled motion, inspired by the motility of natural microorganisms, represents another attractive route for addressing the challenge of nanoscale locomotion. Magnetic nanowire swimmer, which exploits the flexibility of silver artificial flagella for propulsion, can be prepared using template electrodeposition protocol (Figure 5A). Plant-based magnetic helical nanoswimmers are fabricated from spiral microvessels of different plants, harnessing the intrinsic biological structures of Nature (Figure 5B).

Under an alternating magnetic field, they can display a high propulsion velocity in real biological environment, providing an attractive approach for targeted drug delivery: Figure 5C shows microswimmers transport the drug-loaded PLGA nanoparticles to HeLa cancer cells through microchannels.

With such exciting innovations and developments, nano/micromotors are expected to have tremendous impact on diverse biomedical and environmental applications, providing unlimited opportunities limited only by one’s imagination.
Reference