Utilizing Microrobots for Micro-Manipulation, Localized Control, and Cell-Delivery Applications

David Rivas, Sudipta Mallick, Max Sokolich, **Sambeeta Das**

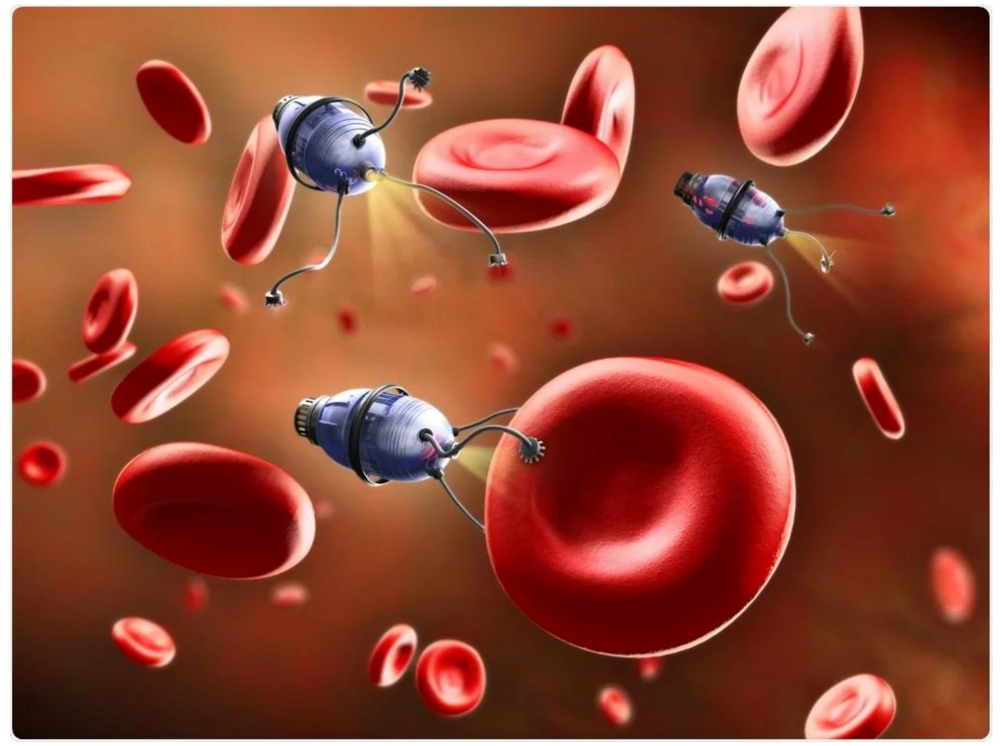
Magnetic Microrobots: Background

Microrobots

Following criteria is used to define a microrobot:
(a) the size of all the features and the overall footprint of the robot is in the range of microns,
(b) surface related forces such as surface tension, drag, viscous forces, brownian motion, etc. dominate motion of the robot, and the inertial forces become negligible because microrobots have a larger surface area compared with their small size.

Microrobotic Actuation

Microbots can be powered by:
(a) A chemical fuel e.g. Hydrogen peroxide
(b) Magnetic field
(c) Light
(d) Acoustic force
(e) Enzymes



Source: Andrea Danti/ Shutterstock

Magnetic actuation mechanisms

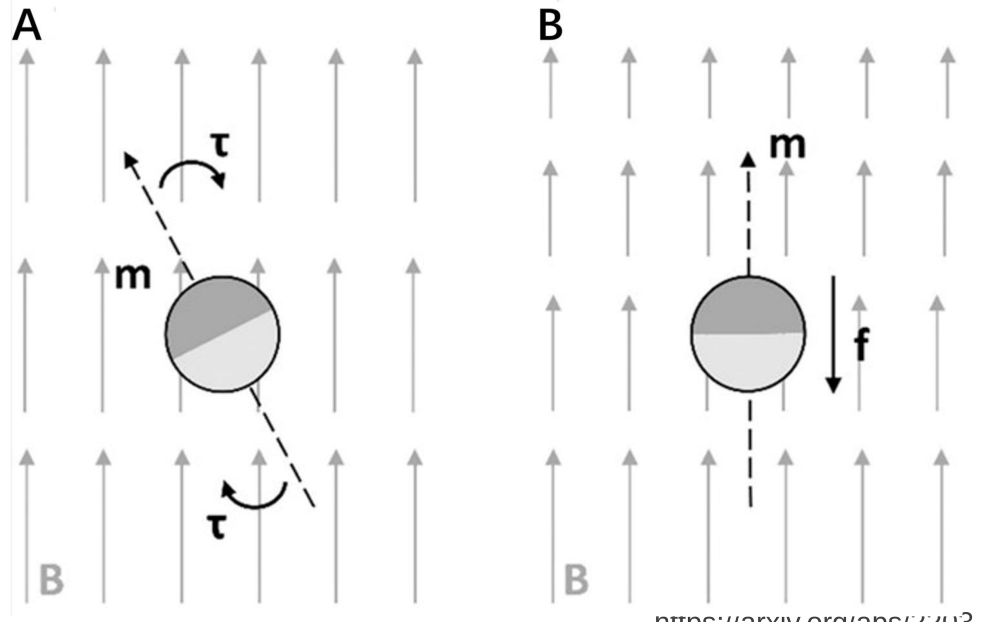
When a microrobot having an embedded magnetic component is placed in a magnetic field, B, it experiences a magnetic force, F.
The magnetic force can be calculated using the following equation:

$$F = (m\nabla)B$$

Where, m is the magnetic dipole moment and ∇ is the gradient of the magnetic field.
When the gradient of B is zero, the microrobot will not experience a magnetic force. The microrobots in a magnetic field also can experience the magnetic torque, τ, which is given by

$$\tau = m \times B$$

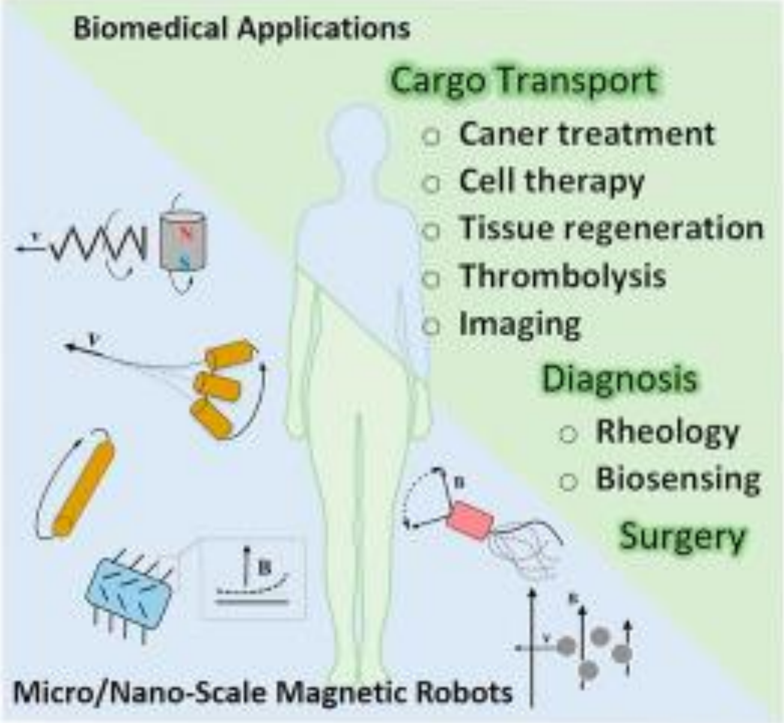
The torque will force the magnetic robot to align its dipole moment with the direction of B.



Advanced Intelligent Systems **2020,** *2* (9), 2000082
https://arxiv.org/abs/2203.13257

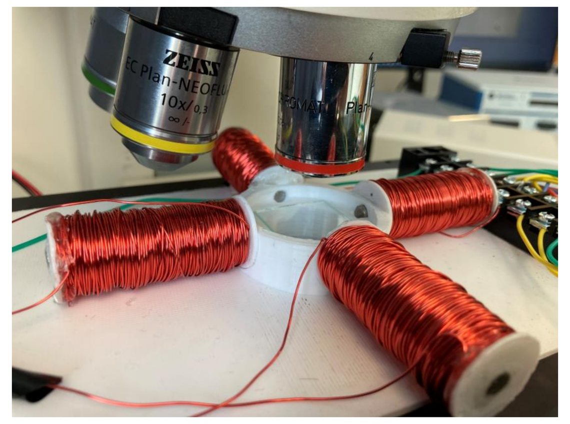
Applications of Magnetic Microrobots

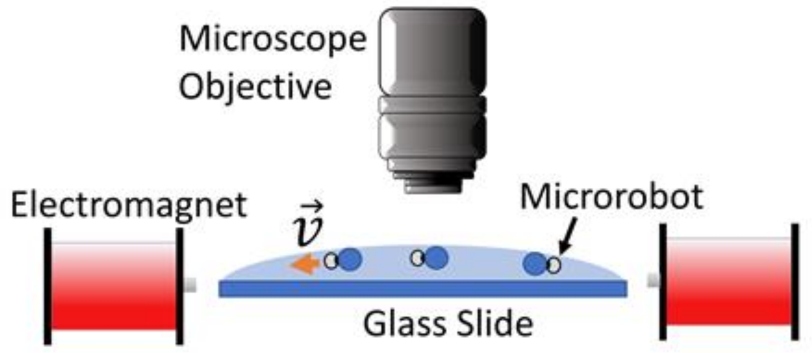
One of the actuation methods that gained attraction in recent years is magnetic actuation because of the numerous factors that make it well suited to actuate and control multiple microrobots.
First, magnetic fields can be employed in opaque and enclosed environments and at large penetration depths. This is unlike some other actuation mechanisms, such as light, which requires a transparent medium.
Secondly, magnetic fields are considered a safe choice to use at the cellular and tissue level for many biomedical applications.
Moreover, high actuation force, compact system size, and low hardware cost also makes it a highly popular actuation technique for microrobots. Additionally, the use of magnetic fields is already a common practice at hospitals, for example, in magnetic resonance imaging devices to diagnose and treat chronic pain syndrome, arthritis, wound healing, insomnia, headache, and several other diseases.



Materials Today Bio **2020,** *8*, 100085

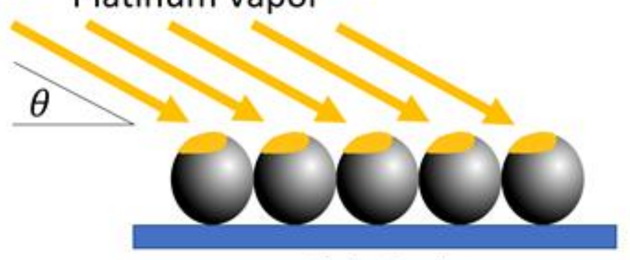
Experimental Setup





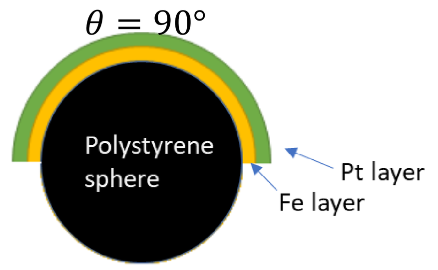
Electromagnets controlled with Xbox joystick

Bubble-Propelled Microrobots for Micromanipulation

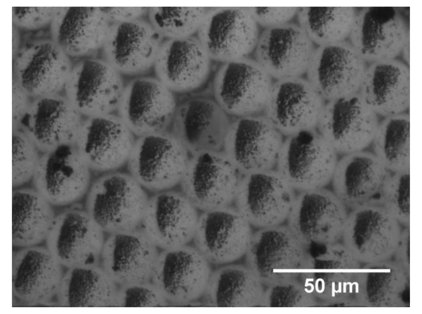


Hemispherical Coating:

$\theta = 10°$

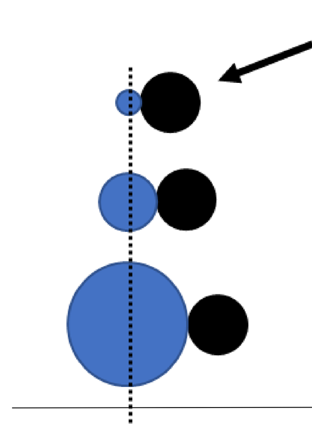


Fluorescent Image of GLAD Coated Spheres



Sphere Diameter: 24 μm

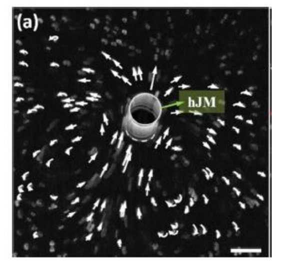
Bubble Growth: Forward Force



M. Manjare, B. Yang, Y.-P. Zhao, Phys. Rev. Lett. 109, 128305 (2012)

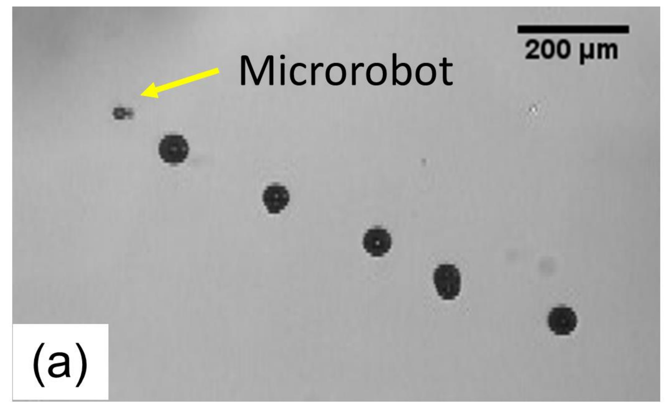
Hydrodynamic Jetting Flow: Forward Force

L.-l. Wang, et al., Langmuir 34, 10426 (2018)



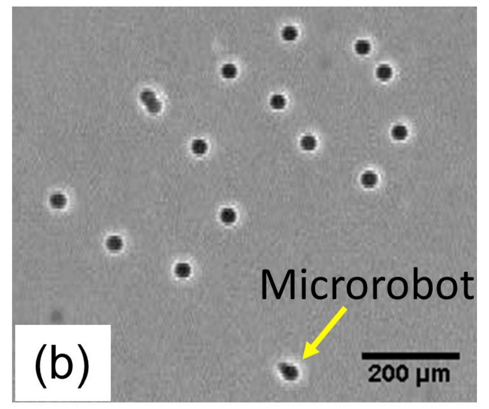
1. D. P. Rivas, M. Sokolich, H. Muller, S. Das, 2022, "Dynamics and Control of Bubble-Propelled Microrobots," Nature Communications, *arXiv preprint arXiv:2203.13257*, submitted

Creating a line of buoyant spheres at the air-liquid interface



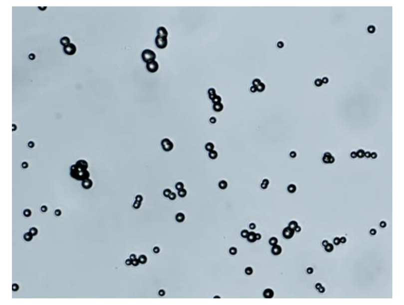
Particle diameter ~ 3 um

Creating the letters "UD" by manipulating passive spheres at the substrate

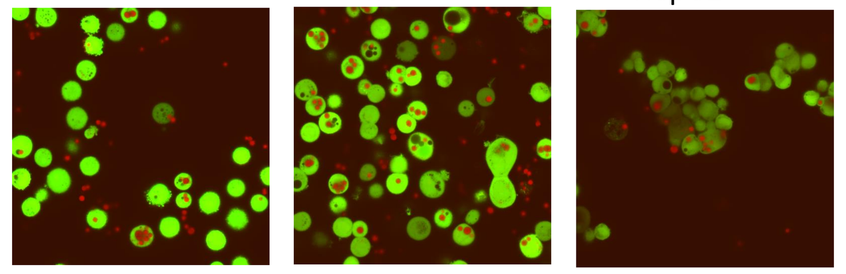


Cellular Expression via Microrobot Delivery

Cellular Uptake in Cancer Cells:



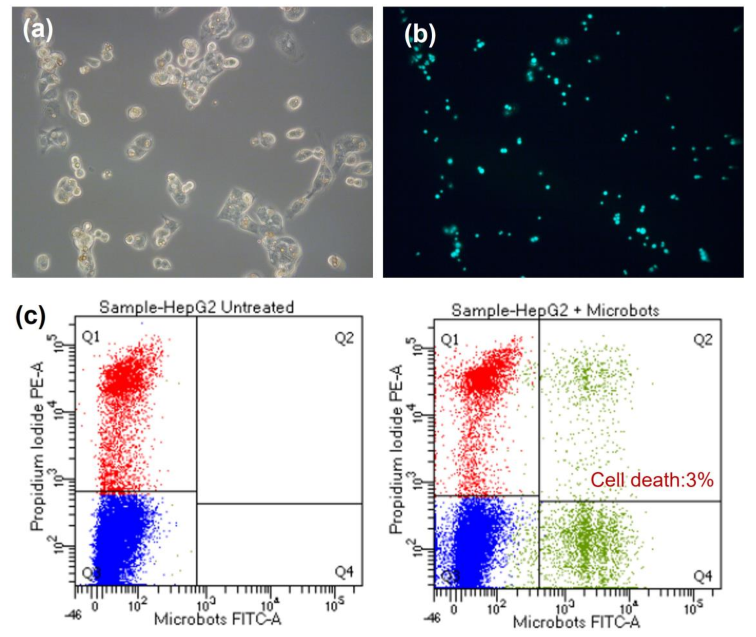
Optical images of microbots (size-4.7µm)



Cell, microrobots

- Cancer cells uptake the microrobots

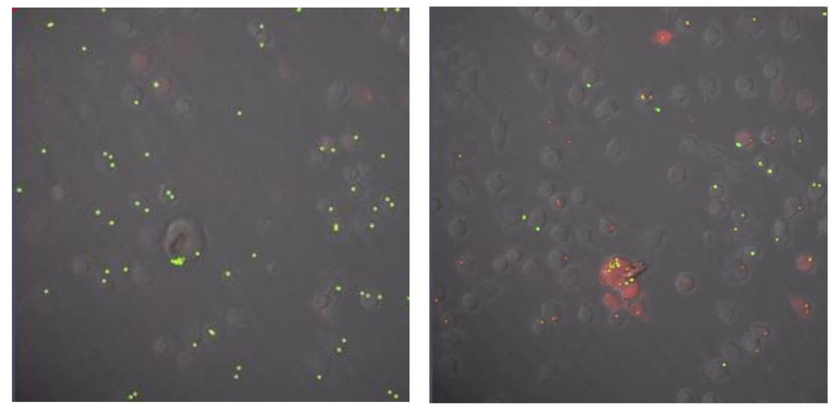
The microrobots themselves are not toxic to the cells



(a) And (b) Bright field and Fluorescence images of cells with Microrobots. (c) Flow cytometry data showing negligible cytotoxicity

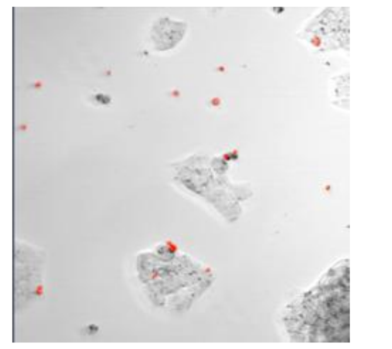
Signaling Molecule Delivery

Microrobots with cells t = 0 t = 12 hrs



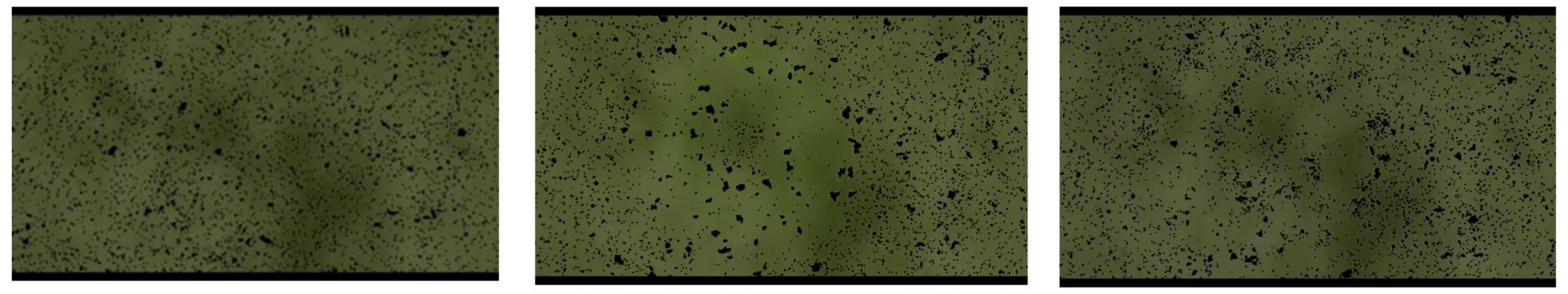
- Microrobots coated with GFP (Green-Fluorescent Protein) are taken up by the cells and cause them to fluoresce

Dox Drug Delivery



1. S. Mallick, M. Sokolich, D. P. Rivas, S. Das, 2022, "Targeted Vibration-Induced Necrosis in Cancer Cells using Paramagnetic Microrobots, Scientific Reports, *https://doi.org/10.1101/2022.10.19.512945*, submitted.
2. D. P. Rivas, S. Mallick, M. Sokolich, S. Das, 2022, "Cellular Manipulation Using Rolling Microrobots," *2022 International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS)*, pp. 1-6

Localized Motility and Aggregation with Patterned Light



Before Light Activation | Aggregation inside the Light Annulus | Dispersal After the Light is Turned Off

- We used a dense collection of light active TiO2 Janus particles to create regions of assembled clusters (inside the light) and a more dispersed gas-like state outside the light. The clumps dissolve readily upon removal of the light.
- Particle diameter – 3 µm

1. S. Mallick, M. Sokolich, D. P. Rivas, S. Das, 2022, "Targeted Vibration-Induced Necrosis in Cancer Cells using Paramagnetic Microrobots, Scientific Reports, *https://doi.org/10.1101/2022.10.19.512945*, submitted.
2. M. Sokolich, D. P. Rivas, Z. H. Shah, S. Das, 2022, "Closed-loop Control of Catalytic Janus Microrobots," Advanced Intelligent Systems, *arXiv preprint arXiv:2210.11460*, submitted
3. M. Sokolich, D. P. Rivas, M. Duey, D. Borsykowsky, S. Das, 2022, "ModMag: A Modular Magnetic Micro-Robotic Manipulation Device", MethodsX, *arXiv preprint arXiv:2211.01173, submitted.*
4. Z.H. Shah, B. Wu, S. Das, 2022, "Multistimuli-responsive Microrobots: a comprehensive review," *Frontiers in Robotics and AI*: 312.

This work is supported by the National Science Foundation under grant number 2020973 and under grant number 2218980.