**Description of the PhD Research Proposal**

# Observation and control of vascular magnetic microrobots.

## 1 Supervision


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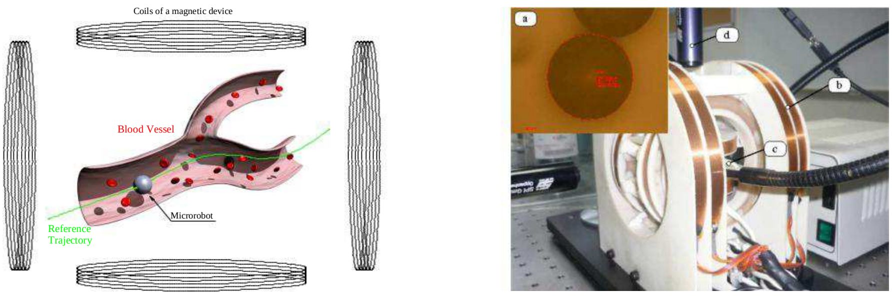
**Keywords**
Observation and control of nonlinear systems, Lyapunov methods, output feedback, para-metric uncertainties, underactuated systems, medical robotics.


## 2 Subject

### 2.1. Context

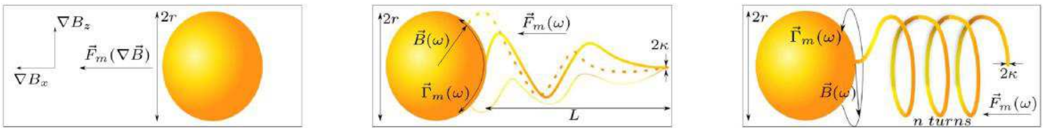



**(a)** **(b)**

*Figure 1: Magnetic actuation of a microrobot navigating in a blood vessel and the labora-tory experimental setup overview: (a) 257µm radius robot, (b) magnetic actuator (three in-ner orthogonal Maxwell coils and one outer Helmholtz coil) from Aeon Scientific www.aeon-scientific.com, (c) workspace, (d) video microscope TIMM400.*

Microrobots are appealing to perform minimally invasive medical procedures: they can reach remote places for in situ biosensing tasks, achieve drug targeting for cancer therapy or microsurgery, with lessened side e□ects with respect to standard medical procedures. To avoid the embedded power supplies load, deported magnetic actuation is considered (see Fig. 1) and enables di□erent untethered magnetic microrobots propulsion designs, as shown in Fig. 2. Wireless power transmission is achieved either by magnetic gradient coils e.g.

MRI devices, or by rotating magnetic coils, depending on the robot design [1]. Imaging is ensured either by the actuator in the case of an MRI device [2] or by another imaging modality (tomography or ultrasound devices).




***(a) Bead pulling.*** ***(b) Elastic flagella.*** ***(c) Helical tail.***

*Figure 2: Different magnetic microrobots propulsion designs. (a) Bead pulling: control input is the magnetic gradient [2, 3, 4]. (c) Elastic flagella: control inputs are the time-average magnetic field direction and the frequency [5, 6]. (c) Helical tail: control inputs are the magnetic torque direction and the frequency [7, 8].*

A microrobot navigating in the vascular network faces, in particular, the blood drag force and the magnetic motive force, resulting in a nonlinear model [9, 10]. The goal is to stabilize the microrobot along a pre-planned reference trajectory, from the robot release point to the medical target. Yet medical imagers measure only the microrobot position: to achieve a stabilizing control law, the other unmeasured states have to be rebuilt, which justify the necessity of an observer. Hence, once a stabilizing controller has been synthesized, the output feedback has to be investigated.

## 4.2 Objectives and proposed approach

The objectives of this PhD thesis are to investigate the following observation and control issues:

- Achieve robustness with respect to output noise inherited from the use of medical imagers whose resolution is limited, and to parametric uncertainties since many biophysical parameters are involved in the model.
- The drag force prevails at a small scale, and is affected by the pulsatile blood velocity, which can hardly be measured in situ. We have already developped a semiglobally stabilizing output feedback in [11, 12]; yet the cardiac pulsation can change due to the patient stress, hence the necessity to extend this approach using an observer for periodic oscillator with unknown frequency [13, 14].
- If a single microrobot can perform diagnosis tasks, it can not carry enough payload to achieve e.g. drug targeting delivery. In this case, it would be necessary to consider a swarm of robots, which is an underactuated system whose observation and control are to be addressed.

## 4.3 Research work plan

- Study existing references on magnetic propulsion and microrobots dynamics modeling.
- Literature review on output feedback and nonlinear underactuated systems.
- Synthesize output feedback for a single microrobot immersed in a pulsatile flow of un-known frequency.
- Synthesize observer and controller to stabilize a swarm of microrobots along a reference trajectory.
- Perform experiments on the laboratory setup (see Fig. 1(b)) to illustrate the efficiency of the proposed approaches.

## References


[1] B. J. Nelson, I. K. Kaliakatsos, and J. J. Abbott, "Microrobots for minimally invasive medecine," *Annual Review of Biomedical Engineering*, vol. 12, pp. 55–85, 2010.

[2] J.-B. Mathieu, G. Beaudoin, and S. Martel, "Method of propulsion of a ferromagnetic core in the cardiovascular system through magnetic gradients generated by an mri system," *IEEE Transactions on Biomedical Engineering*, vol. 53, no. 2, pp. 292–299, 2006.

[3] H. Choi, J. Choi, S. Jeong, C. Yu, J. O. Park, and S. Park, "Two-dimensional locomo-tion of a microrobot with a novel stationary electromagnetic actuation system," *Smart Material and Structures*, vol. 18, p. 115017, 2009.

[4] S. Floyd, C. Pawashe, and M. Sitti, "Two-dimensional contact and noncontact micro-manipulation in liquid using untethered mobile magnetic microrobot," *IEEE Trans-actions on Robotics*, vol. 25, no. 6, pp. 303–308, 2009.

[5] C. H. Wiggins, R. Riveline, A. Ott, and R. E. Goldstein, "Trapping and wiggling: Elas-tohydrodynamics of driven microfilaments," *Biophysical Journal*, vol. 74, pp. 1043– 1060, February 1998.

[6] A. A. Evans and E. Lauga, "Propulsion by passive filaments and active flagella near boundaries," *Physical Review E*, vol. 82(4), p. 041915, 2010.

[7] J. Edd, S. Payen, B. Rubinsky, M. L. Stoller, and M. Sitti, "Biomimetic propulsion for a swimming surgical microrobot," *IEEE International Conference on Intelligent Robots and Systems, Las Vegas*, pp. 2583–2588, 2003.

[8] L. Zhang, K. E. Peyer, and B. J. Nelson, "Artificial bacterial flagella for micromanip-ulation," *Lab on a chip*, vol. 10, no. 17, pp. 2203–2215, 2010.

[9] L. Arcese, M. Fruchard, and A. Ferreira, "Endovascular magnetically-guided robots: navigation modeling and optimization," *IEEE Transactions on Biomedical Engineer-ing*, vol. 59(4), pp. 977–987, 2012.

[10] P. Vartholomeos and C. Mavroidis, "In silico studies of magnetic microparticle ag-gregations in fluid environments for mri-guided drug delivery," *IEEE Transactions on Biomedical Engineering*, vol. 59(11), pp. 3028–3038, 2012.

[11] L. Sadelli, M. Fruchard, and A. Ferreira, "Observer-based controller for microrobot in pulsatile blood flow," *IEEE Conference on Decision and Control (CDC 2014)*, pp. 6993–6998, 2014.

[12] ——, "2d observer-based control of a vascular microrobot," *Submitted to IEEE Trans-actions on Automatic Control*.

[13] V. Andrieu, J.-B. Eytard, and L. Praly, "Dynamic extension without inversion for observers," *IEEE Conference on Decision and Control*, pp. 878 – 883, 2014.

[14] P. Bernard, V. Andrieu, and L. Praly, "Nonlinear observer in the original coordi-nates with diffeomorphism extension and jacobian completion," *Submitted to SIAM J. Control and Optimization*.