– Details of the PhD proposal - INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES CENTRE VAL DE LOIRE

1. Supervision

Name: Antoine FERREIRA, Professor e-mail: antoine.ferreira@insa-cvl.fr

2. Title: Position Control of Magnetic Microrobots Guided by Ultrasound Imaging Feedback.

3. Keywords

Modeling, control of nonlinear systems, ultrasound imaging, medical robotics.

4. Subject

4.1 Context

Recently, robotics at small scales has drawn lots of attention in research both in the fundamental aspects as well as their applications in biomedicine. Many organs in the human body, such as blood vessels and ventricles, are filled with fluid. For efficient actuation in a fluid environment, bioinspired swimming robots, such as the fish, tadpole, and jellyfish, have been proposed. As the characteristic dimensions of the microrobot scaling down to the microscale or even smaller, they have high potential to be navigated in hard-to-reach regions inside human body inaccessible to regular devices and may serve as microrobotic tools for *in vivo* applications such as health monitoring, early diagnosis, targeted therapy and minimally invasive medicine. To avoid the embedded power supplies load, deported magnetic actuation is considered. We developed a electromagnetic system (EMA) to actuate intro three-dimensions a magnetic microrobot by magnetic gradient coils (see Figure 1). Through the control of the magnitude and direction of the current applied to each coil in the EMA system, the microrobot is aligned and propelled in the desired direction.

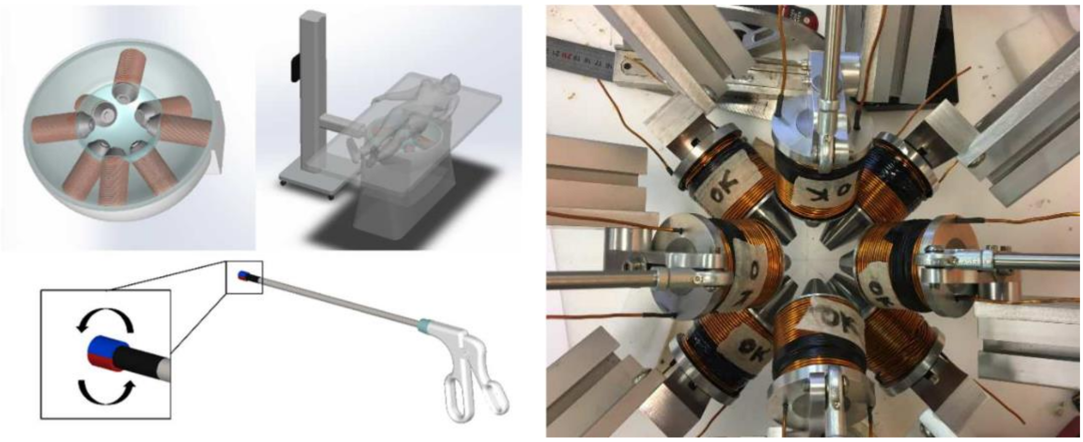

Figure 1. (a) Conceptual illustration of the electromagnetic system and laparoscopic magnetic tool for the magnetic navigation and control of magnetic microrobots for drug delivery.(b) Experimental medical eclectromagnetic platform that has been developed.

The goal is to stabilize the microrobots along a pre-planned reference trajectory, from the robot release point to the medical target. Real-time tracking of the microrobots is essential for the magnetic navigation in blood vessels. Our preliminary results indicate that real-time tracking of the microrobot using ultrasound and the magnetic actuation using an electromagnetic system is feasible. It has been demonstrated that the real-time magnetic navigation of a magnetic-based microrobot using guidance of ultrasound imaging [11] is possible. The microrobot can be generated and navigated using steering gradients or simple rotating magnetic field.

Actually, due to the strong nonlinear models of the electromagnetic system, of the microrobots and the lack of imaging modality, it is difficult to control efficiently the microrobots for targeted therapy. Closed-loop control of microrobot locomotion using ultrasound imaging feedback is a promising solution.

4.2 Objectives

The objectives of this PhD thesis are to investigate the following closed-loop control a magnetically actuated microrobots using two-dimensional ultrasound images. The following issues will be developed :

• Design of a medical magnetic robotic systems for microrobot propulsion;
• Dynamic modeling and state-space representation;
• Robust control of underactuated magnetic actuation systems;
• Position closed-loop control the microrobots using a medical ultrasound imaging system;
• Experimentation of fluidic vascular phantoms for medical validation.

4.3. References

[1] Q. Chao, J. Yu, C. Dai, T. Xu, L. Zhang, C. Wang and X. Jin, “Steering micro-robotic swarm by dynamic actuating fields”, Proc. of 2016 IEEE International Conference on Robotics and Automation (ICRA 2016), Stockholm, Sweden, 2016.

[2] J. F. Yu, T. T. Xu, Z. Y. Lu, C. I. Vong, and L. Zhang, "On-Demand Disassembly of Paramagnetic Nanoparticle Chains for Microrobotic Cargo Delivery," IEEE Transactions on Robotics, vol. 33, pp. 1213-1225, 2017.

[3] J. F. Yu, D. Jin and L. Zhang, “Mobile Magnetic Nanoparticle-based Vortex for Targeted Cargo Delivery in Fluid”, Proc. of 2017 IEEE International Conference on Robotics and Automation (ICRA 2017), Singapore, pp. 6594 - 6599, May 29 - June 3, 2017.

[4] [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.

[5] .-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

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

[7] 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.

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

[9] J. Edd, S. Payen, B. Rubinsky, M. L. Stoller, and M. Sitti, “Biomimetic propulsion for a swimming surgical microrobot,” IEEE Int. Conf. on Int. Robots and Syst., Las Vegas, pp. 2583– 2588, 2003.

[10] L. Arcese, M. Fruchard, and A. Ferreira, “Endovascular magnetically-guided robots: navigation modeling and optimization,” IEEE Transactions on Biomedical Engineering, vol. 59(4), pp. 977–987, 2012.

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

5. Academic skills: Robust control, dynamic modeling, robotics. Imaging processing techniques will be appreciated.

6. Institution: Laboratoire PRISME – INSA Centre Val de Loire – 88 Boulevard Lahitolle – 18000 – Bourges (https://www.insa-centrevaldeloire.fr/en)