Internship Opportunity

Modeling and controlled motion of biological cells by dielectrophoresis using the port Hamiltonian framework.

I Subject

Modeling and controlled motion of biological cells (10µm of diameter) by dielectrophoresis using the port Hamiltonian framework.

Key words : Modeling, control, dielectrophoresis, port Hamiltonian systems, nonlinear system, partial derivative equations

II Context

The contactless manipulation of micro-objects has drowned researcher's interest because it enables:

- high precision and dynamics as no mechanical part are involved
- non invasive manipulation that enables to avoid contamination (important for the case of the manipulation of biological objects)
- to overcome the issue of interaction forces between the effector and the manipulated object (hard to model, non linear)

Those methods rely on the use of force fields (such as electromagnetic and acoustic fields) and use control method to regulate the shape of those fields and their gradient and consequently, the force exerted on the microrobots. This type of manipulation requires precise model of the force field and the predominant forces at the microscale level as well as performant control laws that can be based on feedforward and closed-loop control through H infinity, predictive control, energy shaping, etc.

The use of electric field to induce dielectrophoretic force on microscale objects is studied in the AS2M department [1, 2, 3]. Briefly, a dielectric object inside a non-uniform electric field will polarize and experience a dipole moment that will induce a force on it. The systems used to perform those manipulations are microchips with several electrodes, as shown in fig.1. The voltage on each electrode is controlled to shape the electric field. It is a system with distributed inputs, including partial derivative equations, non-linearties and varying boundary conditions.

To handle the aforementioned difficulties, the port-Hamiltonian approach will be employed. It is based on the principle of conservation of energy and exhibits the system's passivity properties and provides a clear physical interpretation of control design strategies [4, 5, 6].The port Hamiltonian formulation is particularly well-adapted for this type of systems implying non-linearties, multi-physics and partial differential equations.

This internship will firstly focus on the modeling of the electric field and the phenomenon of dielectrophoresis using the port Hamiltonian formulation. Then, the control design method will be investigated to regulate the position of the object. Finally, simulations or/and real experiments will be carried out to validate the proposed model to demonstrate the effectiveness of the proposed control method.

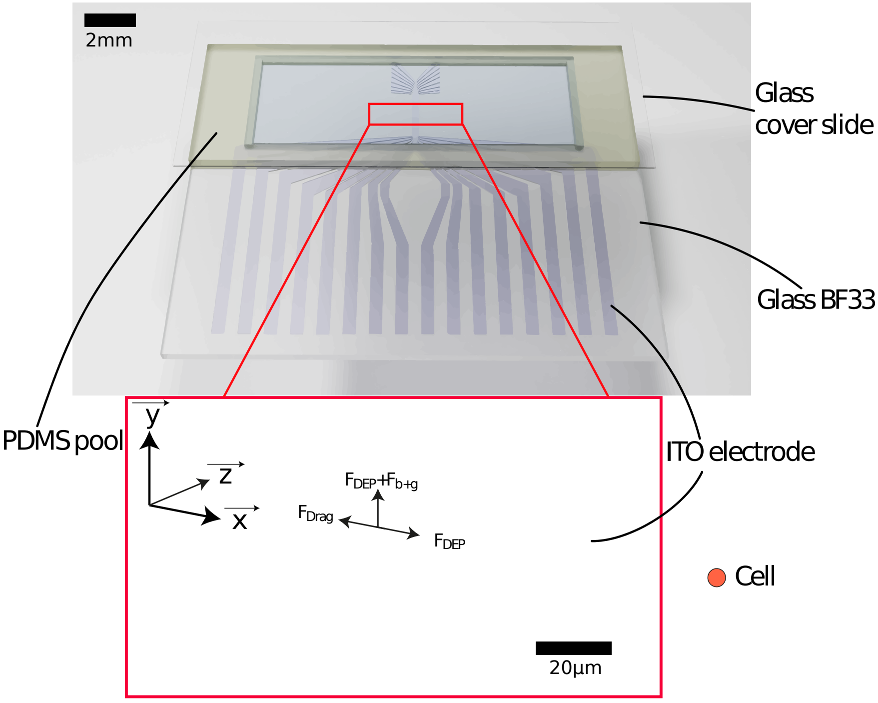

Figure 1: Description of a system to control. It is composed of a glass substrate on which electrodes have been deposited. The voltages applied on those electrodes is used to generate the electric field and induce a force on the object.

III Work plan

The objective of this internship is to propose a control method based on the port Hamiltonian framework for the 2D controlled motion of a microscale object using electric fields.

The port Hamiltonian formulation is particularly well-adapted for this type of systems implying non-linearties and partial differential equations. This type of port based modeling is also suited to consider interactions between several objects or simultaneous control of several objects, which are both of interest for biomedical applications. It has been used to model and control systems based on uniform electric field but the formulation for nonuniform electric field and the induced process of polarization of objects need to be studied.

The step of this internship are the following ones :

1. Review of the literature on the modeling of electric fields and the phenomenon of dielectrophoresis using the port Hamiltonian approach. Review of literature on energy based control methods
2. Definition of the considered system with reasonable physical assumptions
3. Modeling for the motion of a spherical object in 1D with the assumption of electrostatic conditions and only two electrodes

4. Simulation of the proposed model and comparison to existing ones in the literature
5. Increase the number of electrodes, consider 2D and perform simulations
6. Propose energy-base control methods to regulate the position of the object by controlling the voltages on each electrode of the system
7. Perform validation of the proposed control method through simulations and/or experiments

IV Internship Information

The AS2M department of the FEMTO-ST Institute is specialized in microrobotics and micro-mechatronics. It investigates, since more than 10 years, the design, modeling, fabrication, and control of microsystems and microrobots. Various systems have been achieved for micro-assembly [7, 8] and biomedical applications [9, 10] using several actuation and sensing methods adapted to microsystems [11].

Date : Starts from February/March 2025 and end on July/August 2025.
Location : AS2M department of the FEMTO-ST institute which is hosted inside the engineering school SUPMICROTECH.
Gratification : Legal rate, approximately 550€/month for 6 months.

V Supervision team

- Dr. Alexis Lefevre : Alexis.lefevre@femto-st.fr
- Dr. Yongxin Wu : yongxin.wu@femto-st.fr
- Pr. Yann Le Gorrec : legorrec@femto-st.fr

VI Applications

The following candidate profiles are expected for this internship: Automatic control, mechatronics, Robotics, etc.

The candidate has to send his/her CV and a cover letter to Dr. Alexis Lefevre. The application of the internship will be closed the 20^{th} of December 2024.

References

[1] A. Lefevre, V. Gauthier, M. Gauthier, and A. Bolopion, "Closed-Loop Control of Particles Based on Dielectrophoretic Actuation," *IEEE/ASME Transactions on Mechatronics*, vol. 27, no. 6, pp. 4764–4773.

[2] A. Lefevre, C. Brandi, A. De Ninno, F. Ruggiero, E. Verona, M. Gauthier, P. Bisegna, A. Bolopion, and F. Caselli, "Real-time impedance-activated dielectrophoretic actuation for reconfigurable manipulation of single flowing particles," *Lab on a Chip*.

[3] C. Lipp, L. Koebel, A. Bertsch, M. Gauthier, A. Bolopion, and P. Renaud, "Dielectrophoretic traps for efficient bead and cell trapping and formation of aggregates of controlled size and composition," *Frontiers in Bioengineering and Biotechnology*, vol. 10, p. 910578.

[4] A. Macchelli, Y. Le Gorrec, H. Ramirez, and H. Zwart, “On the synthesis of boundary control laws for distributed port-hamiltonian systems,” *IEEE Transactions on Automatic Control*, vol. 62, no. 4, pp. 1700–1713.

[5] N. Cisneros, Y. Wu, K. Rabenorosoa, and Y. Le Gorrec, “Port-Hamiltonian modeling and control of a curling HASEL actuator,” *IFAC-PapersOnLine*, vol. 58, no. 6, pp. 143–148.

[6] “Port-Hamiltonian Systems Theory: An Introductory Overview.”

[7] J. Agnus, N. Chaillet, C. Clévy, S. Dembélé, M. Gauthier, Y. Haddab, G. Laurent, P. Lutz, N. Piat, K. Rabenorosoa, M. Rakotondrabe, and B. Tamadazte, “Robotic microassembly and micromanipulation at FEMTO-ST,” *Journal of Micro-Bio Robotics*, vol. 8, no. 2, pp. 91–106.

[8] F. N. Piñan Basualdo, A. Bolopion, M. Gauthier, and P. Lambert, “A microrobotic platform actuated by thermocapillary flows for manipulation at the air-water interface,” *Science Robotics*, vol. 6, no. 52, p. eabd3557.

[9] B. Ahmad, A. Barbot, G. Ulliac, and A. Bolopion, “Remotely actuated optothermal robotic microjoints based on spiral bimaterial design,” *IEEE/ASME Transactions on Mechatronics*, vol. 27, no. 5, pp. 4090–4100.

[10] C. Lipp, L. Koebel, R. Loyon, A. Bolopion, L. Spehner, M. Gauthier, C. Borg, A. Bertsch, and P. Renaud, “Controlled Contact between Beads and Cells for the Characterization of Receptor–Ligand Bonds,” in *Proceedings*, vol. 97, p. 189, MDPI.

[11] A. Castellanos, A. Ramos, A. González, N. G. Green, and H. Morgan, “Electrohydrodynamics and dielectrophoresis in microsystems: Scaling laws,” *Journal of Physics D: Applied Physics*, vol. 36, no. 20, pp. 2584–2597.