ULB, TIPs department (in collaboration with BEAMS and 4MAT)

Master Thesis and Internships

Applied physics, soft/wet microrobotics and biomedical topics

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31/03/2021
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Cleaning optical lenses from biological fluids in endoscopy (+internship in LysMedical (Waterloo (BE))

**Promotors:** Pierre Lambert

**Supervisors:** Loïc Amez-Droz (glass microstructuration), Matéo Tunon de Lara (chemistry), Franco Piñan Basualdo (thermocapillary solutions), Joël De Coninck (wetting)

**Context:**

There is a variety of applications requiring to remove water droplets from transparent surfaces: cleaning solar cells, removing rain droplets from cameras or biological liquids from endoscope’s lenses. Lenses are mostly made of glass, which is an hydrophilic materials. Water-based droplets and liquids therefore tend to wet these surfaces because of minimal surface energy considerations. These wetting properties are the result from properties of surfaces (surface energy) and liquids (surface tension). Therefore, literature mentions methods to (re)move droplets from a surface by changing this surface energy: hydrophobic coatings combined with some shear stress (air on a windshield), electrowetting (using electric field to deform and displace droplets – [Lee2017, Chung2019]), wettability gradients and vibrations to displace droplets towards lower surface energy area [Sun2020]. It is also possible to tune surface tension with chemicals (surfactants) or temperature gradients (thermocapillary effect) [Piñan2021].

**Figure:** Removal rain droplets from a camera for automobile [Lee2017]

**Goals:**

The goal of this internship and this master thesis is to develop a solution to actively or passively clean an optical lens with a few millimeters diameter. The student will propose and tests the most promising solutions combining the requirements expressed by the Belgian company Lys Medical, the solutions mentioned in literature and the tools available at ULB (coatings, surface texturation of glass, thermocapillary effects triggered with an infrared laser).

**Tasks:**

Literature survey, requirements analysis (biocompatibility, size, usages...), experimental tests (hydrophobic coatings, wetting gradients, piezo-shakers, thermocapillary removal of droplets, electrowetting solutions...). The tests will be done in the company, the coatings and glass structuration will be done in ULB/TIPS.

[Piñan2021] F. Piñan Basualdo, A. Bolopion, M. Gauthier, P. Lambert, A microrobotic platform actuated by thermocapillary flows for manipulation at the air-water interface, to be published in Science Robotics, 31st March 2021
[Sun2020] D. Sun, K. Boehringer, An active self-cleaning surface system for photovoltaic modules using anisotropic ratchet conveyors and mechanical vibrations, Microsystems and Nanoengineering, 6(1), 87 (2020)
Moving droplets with thermal gradients

Promotors: Pierre Lambert
Supervisors: Loïc Amez-Droz (glass microstructuration), Franco Piñan Basualdo (thermocapillary solutions), Joël De Coninck (wetting)

Context:
Condensation is a key process for spatial application, in particular in heat transfer. However, condensed droplets should be continuously removed. In the absence of gravity, droplets can be displaced however thanks to wettability gradients patterned on the surface of the condenser, which create a spontaneous driving force to remove the droplets. Beside wettability gradients on surfaces, it is also possible to create surface tension gradients on the droplet-air interface thanks to the heat generation obtained by the absorption of an infrared laser (the absorption peak of water is about 1.455µm). The optimization question is to maximizes the droplets removal flow rate. To this aim, wetting science provides many useful models [Dussan1979, DeGennes1985, Blake2006,Bonn2009,Snoeijer2013,Moumen2006, Subramanian2005].

Goals:
In this project, we propose to study experimentally the displacement of droplets on different substrates thanks to thermal gradients. The droplet velocity can be predicted by [Brochard1989]:

$$\eta V = \frac{2\gamma_0}{3\eta\varepsilon_n} \left( \frac{d}{dT}(\gamma_{SO} - \gamma_{SL}) + \frac{1}{2} \frac{d\gamma}{dT} \frac{dT}{dx} \right)$$  

(36)

Two questions will be addressed: can we validate this theory experimentally? Can it be used to optimize the droplets displacement?

Tasks:
- Prepare surfaces with coatings (Silicone, Teflon, Silanes) and texturation (glass microstructuration with FemtoPrint)
- Develop the tools to monitor the drop position in real time and closed-loop control the laser position
- Measure temperatures with IR camera

Surface Tension Microrobotics (+internship in FEMTO-ST, Besançon (FR))

Promotor: Pierre Lambert  
Internship contact: Antoine Barbot (antoine.barbot@femto-st.fr)

Context:

At scales lower than 1 mm, surface tension forces overcome gravity and inertia forces. Therefore, they have a strong potential for the design of efficient actuators below the millimetre [4], and also have been proven to be efficient for pick and place of small objects [3, 2]. However the dynamic interaction between the fluid interface and solid object floating at the interface is more complex to understand and control than a standard mechanical joint. This is mainly due to the deformation of the liquid interface that introduces a high number degree of freedom in the system.

Figure: example of capillary motor (Credits Atsushi Takei, University of Tokyo)

Goals:

- The goal of the internship is to develop a static model of the droplet sandwiched between the “stator” (on the substrate) and the “rotor” (the floating plate), to derive the forces and torques developed as a function of the geometry. This would allow to find the correct geometry of object floating on fluid interfaces depending on the desire mechanical property.
- The goal of the master thesis is to push the study forward with some static experiments, by printing stators and rotors of various geometry with 3D printing and materials (photolithography, nanoscribe, femtoprint). Dynamics can be considered as well according to the project advancement: mode characterization, comsol simulation, actuation with external stimuli: magnetic field on the rotor, or electric field or light on the drop.

Tasks:

- Simulation: Surface Evolver [1] solver to model a drop position with \( x \) position of the solid floating object. Secondly, model the trajectory of the floating object by interfacing a quasi-static integration of the floating object position. Thirdly, use the model to optimize floating object geometry. Finally, experimental validation of optimised design using 2 photon lithography will be investigated.
- Experiments: build a set up to image the capillary motor, and optionally to measure forces and torques, build/use a set up to apply external stimuli and characterize step responses

The student should have a basic knowledge in a least one programming language (Python,C++,matlab) and Good physics and analytical skills. Basic knowledge on numerical simulation method would be appreciated but are not mandatory.

References:

Stretching and rupture of fluid films and filaments

Promotors: Benoît Scheid, Pierre Lambert
Supervisor: Joël De Coninck, Adam Chafai

Context:
Stretching liquid films and filaments is an important industrial process, for instance to draw polymer fibers, or to stretch and break liquid menisci in printing industries. There are many underlying questions: thickness or diameters as a function of gravity, viscosity, velocity, surface tension, rupture conditions, liquid repartition... An important open question is the influence of wetting boundary conditions on both sides of the film or filament: boundary conditions on the wetting (contact angles) conditions, presence of defects, pressure and velocity conditions. The effect of these boundary conditions can be studied experimentally, or digitally (with fluid mechanics simulations or molecular dynamics simulations).

![Figure: Stretching of a meniscus with a linear motor (Credits: Adam Chafai, TIPS)](image)

Goals:
Molecular dynamics simulations will be used to study in detail the boundary conditions between the two solid surfaces and the liquid meniscus. The results will be provided to the concerned student. From these boundary conditions and fixing the height between the fiber and the solid surface, it is possible to model the system at equilibrium using COMSOL and to test the validity of the model comparing the results to experimental data. The last step is to consider some stretching of the meniscus due to a displacement of the fiber with a linear motor (acceleration up to 150 m/s²).

Can we predict the rupture of the meniscus? And therefore the quantity of liquid remaining on the solid surface? The solution of this problem would help scientists to design drop experiments in space conditions.

Tasks:

Experimental
- Build a set up combining actuators and imaging
- Characterize inputs: liquids surface tension, viscosity, velocities
- Measure outputs: rupture height, volume repartition

Computational
- Molecular dynamics
- Comsol
Soft sensor for soft robotics

Promoters: Pierre Lambert (TIPs) – Alain Delchambre (BEAMS)
Supervisor: Gilles Decroly – gilles.decroly@ulb.be, Martin Brandenbourger

Description: Soft robots could open many new opportunities because of their softness, safety, and ability to achieve complex movements. However, given the infinite number of freedoms and large deformations of compliant actuators, the lack of adapted self-sensing and feedback methods makes difficult the rise of new applications.

This work aims at developing embedded soft sensors for modular soft actuators. Several transducer mechanisms for strain sensing have been proposed to meet the required softness and large deformations [1, 2]. Among them, using resistive sensors made of liquid metal embedded in silicone seem especially interesting for its easy integration in soft actuators [3, 4]. In previous work, we developed what we call voxels actuators, i.e., actuators able of one simple kinematics (bending, elongation, compression, shear, or twisting). By assembling them modularly, soft robots able complex motions for specific tasks could be obtained. Adding self-sensing capabilities to these voxels could open new opportunities in term of actuation and control.

Goal: The objectives of this master thesis are (1) to select and develop a soft sensor based on the literature and (2) implement them in the previously developed voxels actuator to characterize their “pure” deformation. This will require to make a complete state of the art comparing the different sensing solutions, and an important experimental part for the fabrication and characterization of the soft sensors and their integration in voxels.

Tasks:

- Literature review / state of the art / understanding of the project / quantification of the requirements
- Selection, fabrication, experimental study, and characterization of the soft sensor (moulding, laser-cutting, design of experiment, building test benches, …)
- Based on the literature and on eventual modelling, integration of the soft sensor in the previously developed voxel actuators to measure deformations along a given degree of freedom.

[3] https://www.youtube.com/watch?v=gSI_UMDhSaw
Materials with designed viscoelastic properties

**Promoters:** Pierre Lambert (TIPs)

**Supervisor:** Martin Brandenbourger - martin.brandenbourger@ulb.be, Gilles Decroly

**Description:**

The mechanical properties of materials are not only determined by their chemical composition, but also by their structure. Mechanical metamaterials are materials with repetitive structures specifically designed to control mechanical properties such as the Poisson’s ratio. A recent exciting trend consists in controlling the viscoelastic properties of a material with such structures in order to precisely tune its dynamical response [1,2].

This project aims at designing materials with precisely tuned viscoelastic properties and use these viscoelastic properties to control the absorption of shocks. These viscoelastic metamaterials will consist in soft structured materials encapsulating a viscous liquid. Fig. 1A gives a very first example of a passive soft solid with empty chambers in which liquid can be encapsulated. Beyond this first example, this project will also study how asymmetries in the structure of the mechanical metamaterial (Fig. 1b) can lead to asymmetric responses. This is highlighted in Fig. 1c by the deflection of a projectile during an impact on the metamaterial.

**Goal:** The objectives of this master thesis are (1) to develop design rules to precisely control the viscoelastic properties of a viscoelastic metamaterial by combining liquid and solid phases (2) to study how asymmetric structures within the viscoelastic metamaterials enable a fine control of the impact of a projectile.

**Tasks:**

- Literature review / state of the art / understanding of the project / quantification of the requirements
- Fabrication, experimental study, and characterization of the viscoelastic metamaterial (molding, design of experiment, building test benches, ...)
- Develop a method to characterize the response of the developed viscoelastic metamaterials to the impact of a projectile.


In vitro study of nose-to-brain drug delivery using nasal replicas (+internship in the Pharmaceutic Technology and Biopharmacy of Kiel University, Kiel, Germany)

Promotors: Benoit Haut & Pierre Lambert

Internship contact: Prof. Regina Scherließ, rscherliess@pharmazie.uni-kiel.de, https://www.pharmazie.uni-kiel.de/de/pharmazeutische-technologie-und-biopharmazie

Supervisor: Louis Van Hove – louis.van.hove@ulb.be

Description: Nose-to-brain drug delivery is a very promising way to deliver drugs. For this purpose, the airflow generated by a spray device must convey the drug particles through the nose and deposit them in the so-called olfactory area. Since each patient nose anatomy is different, this process must be optimized to become patient specific. This work would be the follow up of an ongoing master’s thesis. This thesis allowed to develop nasal replicas and artificial mucus which are intended to be used for the study of drug deposition.

Goal of the internship: the internship aims at using a nasal cast available in U Kiel to characterize the drug deposition and further use these data as a benchmark in the master thesis. It is also an opportunity to bring engineering skills in a pharmacy scientists group.

Goal of the master thesis: The thesis aims to measure the quantity of drug deposited in the olfactory region regarding different parameters such as the delivery procedure, the placement of the spray device in the nose or other parameters. The goal of this study is to provide insights for the optimisation of drug delivery in the nasal cavity.

Tasks of the master thesis:

- Literature review / state of the art
- Measure of drug deposition as a function of different parameters
- Draw the first guiding lines to optimise nasal drug delivery


[3] Calmet et al. ‘Nasal sprayed particle deposition in a human nasal cavity under different inhalation conditions’, PLOS ONE, 2019
CFD simulations in the field of nose-to-brain drug delivery

**Promotors:** Benoit Haut & Pierre Lambert

**Supervisor:** Clément Rigaut - clement.rigaut@ulb.be

**Description:** Nose-to-brain drug delivery is a very promising way to deliver drugs. For this purpose, the airflow generated by a spray device must convey the drug particles through the nose and deposit them in the so-called olfactory area. Since each patient nose anatomy is different, this process must be optimized to become patient specific.

**Goals:** This thesis consists of the simulation of a pressure-driven flow in the nasal cavity. This flow must be determined for different boundary condition such as normal breathing, forced inspiration, closing of one nostrils, etc. These simulations can be combined with simulations of a spray to assess the deposition profile of a fine powder in the nose.

**Tasks:**

- Literature review / state of the art
- Model the nasal cavity using a CFD software (Ansys-Fluent or OpenFOAM).
- Analyse the flow and spray deposition in the cavity under different breath patterns

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[3] Calmet et al. ‘Nasal sprayed particle deposition in a human nasal cavity under different inhalation conditions’, PLOS ONE, 2019
Using magneto-capillary assemblies to characterize the effect of a laser-induced thermocapillary flow on floating particles

**Promotors:** Pierre Lambert  
**Supervisor:** Franco Piñan Basualdo - fpinanba@ulb.ac.be

**Context:** When similar particles float at the air-water interface, they attract each other due to the Cheerios effect [1], the effect behind the clumping of cereals on top of a bowl of milk. If we induce a vertical magnetic field, floating paramagnetic particles will repel each other due to the magnetic dipole-dipole interaction. These two effects cancel one another at a given inter-particle distance, leading to the formation of crystal-like assemblies [2].

On the other hand, we can use an infrared laser to locally heat the interface, triggering a thermocapillary flow that can be used to manipulate floating objects [3,4]. The laser-induced thermocapillary flow has been thoroughly studied and the precise control of floating objects has been achieved based on empirical characterisations, but there is a missing link: the effect of the flow on the particles (force) measurement and model.

**Goals:** The objective of this work is to estimate the force exerted by the thermocapillary flow on the particles by measuring its effect on magneto-capillary assemblies. We have observed that under some specific configurations, we can modify the equilibrium interparticle distance using the laser. By modifying both the laser power and the magnetic field intensity, we hope to estimate the force exerted by the thermocapillary flow.

**Tasks:**

- Literature review / state of the art.
- Measurement if the inter-particle distance (through image analysis) as a function of the laser power and magnetic field intensity under some configurations.
- Use of the previously obtained results and our knowledge on magneto-capillary assemblies to elucidate the force exerted by the thermocapillary flow.


Surface state enhancement for glass micro-structures manufactured with a femtosecond laser.

Promotors: Pierre Lambert (TIPs), Stephane Godet (4MAT)
Supervisors: Adam Chafai, Mateo Tunon de Lara, Loïc Amez-Droz

Context: High-precision glass micro-structures can be obtained by subtractive manufacturing using a femtosecond laser. After being locally exposed to the laser radiation, the fused silica glass (a-SiO₂) is chemically etched. Due to the excellent elastic and optical properties of a-SiO₂, this technology finds numerous applications in the fields of micromechanics (e.g. force sensors), optics (e.g. optical fibers), microfluidics (e.g. complex microchannels) [Bellouard2012]. However, the performance of these systems is limited, inter alia, by the surface state. When a polishing step is impossible, strategies must be found to enhance the surface state.

Goals: With the conjoined expertise of the TIPs and 4MAT laboratories, the goal of this master thesis is to develop manufacturing strategies to enhance the surface state and other critical aspects of the manufacturing through characterizations and optimization of the Femtoprint machine. The characterization will be achieved with metrology tools (profilometry, scanning electron microscopy). The optimization of the identified critical aspects will be based on the understanding of the manufacturing technology and on the Design of Experiment method [Montgomery2019]. Attending the MECA-H501 soft-microrobotics course is therefore strongly advised.

Tasks: Literature review; design of the test samples and end-to-end manufacturing on the FemtoPrint; surface state analysis; optimization of the key parameters of the process; development of a manufacturing strategy enhancing the surface state without sacrificing too much manufacturing speed (rough and finish passes method for milling machines).

Fig.: (a) Glass micro-joint in deflection, yielding a pure rotation of the blade (credits: L. Amez-Droz, TIPs); (b) 3D confocal microscopy of the surface state of a glass structure.

Development of a glass flexure based kinematic mirror mechanism for a compact interferometer

Promotor: Pierre Lambert  
Supervisor: Loïc Amez-Droz

Context:

Kinematic mirror mounts are used in a variety of optics application such as in interferometry (fig. 1 POLARIS kinematic mount in Cooper’s compact interferometer). The purpose of the mirror kinematic mount is to allow mirror orientation adjustments to align the light path with other optical components. Mirror kinematic mechanisms appear in almost every size orders. However, the technologies from a dimension order to another are very different. Mirror mount adjustment mechanisms minimum size is limited by the complexity of small parts machining and assembly at a reasonable price and the maximum size of micro-mirrors is limited by the microelectromechanical systems (MEMS) fabrication technique. Thanks to the FEMTOprint machine available at ULB, 3D printed micro-devices out of glass (fused silica) with submicron resolution can be obtained. Considering the outstanding properties of glass like its optical quality surface finish potential and its high elastic limit to Young modulus ratio, a monolithic flexure based kinematic mirror mechanism can be obtained. Reflective material coating on fused silica will permit to get the mirror surface on the structure.

Goals:

The goal of this project is to design a flexure mechanism considering the required mirror angular compliances, the minimum stiffness to prevent mirror vibration in the operating range and the manufacturing limitations. The student will propose the most promising design according to numerical movement behavior simulations. Then, a prototype will be manufactured by the laboratory scientists. As an extra step, the student will be able to discuss and propose an adjuster mechanism solution with the help of the scientists.

Tasks:

- Literature survey, requirements analysis (adjustment compliances, operating range, strength...), kinematics description, computer aided design (CAD), numerical simulations (static, dynamic, using finite element analysis), experimental characterization


Development of a two-axis force sensor array to measure the adhesion forces of an ant’s legs

Promotor: Pierre Lambert, Supervisor: Loïc Amez-Droz

Context:

The locomotion ability of the insects is an example to further improve motion technologies such as microdevices and microrobots. Indeed, their capacity to adhere to a surface and leave it quickly allows the ants to perform agile manoeuvres. There are interesting studies on the subject such as the work of Nguyen on MEMS or the work of Bonchart and Gravet who proposed a design inspired by Buttafuoco’s sensor to get a two-axis force sensor independent of the application position of the force. New technology is available at ULB to print 3D micro-devices out of glass (fused silica) with submicron resolution. Considering the outstanding properties of glass, like its low loss factor, its low thermal expansion and its high elastic limit to Young modulus ratio, a high-resolution monolithic flexure sensor array can be obtained.

Takahashi 2014, Ant force sensor array
Bonchart & Gravet 2013, two-axis improved force sensor
Amez-Droz 2021, Fused silica flexure pivot

Goals:

The goal of this project is to design a two-axis flexure force sensor unit. This mechanism shall be optimized such as it can be multiplied and arranged creating a flat sensing surface minimizing the unusable space between each of them. The student will propose its most promising design and a review of the applicable sensing methods to measure the forces. Then, a prototype will be manufactured by laboratory scientists. As an extra step, the student will be able to design a test bench to characterize its sensor unit prototype with the help of the scientists.

Tasks:

Literature survey, requirements analysis (sensor sensibility, operating range, manufacturability...), kinematics description, analytical model, computer aided design (CAD), numerical simulations (static, dynamic, using finite element analysis), experimental characterization

Microfabrication complexes optical shapes by using a femtoprint machine

**Promoters:** Pierre Lambert (ULB), Christophe Caucheteur (UMons)

**Supervisors:** Mateo Tunon de Lara (mateo.tunon.de.lara.ramos@ulb.be; 535475@umons.ac.be)

**Context:**

Among the large variety of laser technologies, the femtosecond laser is a very high repetition rate laser (up to 1MHz). It is usually used to create default in all kinds of glass or fibre, or even to micromachine glass parts in 3D at the microscale. The Femtoprint[1] machine relies on these principles, exhibiting many different parameters that can be adjusted very easily towards many different applications[2] targeting mechanical or optical domains.[3]

**Goals:**

The goal is to design, produce and optimize different complex optical structures: first waveguides[4] with complexes shapes, then a beam splitter to be used in an interferometry set up.

![Waveguide Example](image)

Figure: (A) Straight single mode waveguide and S-bend written in fused silica (single-mode at 670 nm); (B) Schematic of the experimental setup and the produced three-dimensional splitter; (C) Near-field intensity distribution at 1.05 μm measured at the exit of the splitter.

**Tasks:**

Literature review, Microscope, Femtosecond machining including writing of script with the alphacam software, optical path measurements

**References**