ULB, TIPs department

Master Thesis and Internships

Applied physics, soft/wet microrobotics, photonics, precision mechanics, wetting, nose-to-brain drug delivery, and biomedical topics

Clément RIGAUT, Manon CASSIGNOL, Margaux MANNAERTS, Pierre LAMBERT
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Table des matières

Instrumented glass gripper: Percipio Robotics' Tulip gripper revisited (+ internship – to be confirmed by the company Percipio Robotics)

Supervisor Pierre LAMBERT pierre.lambert@ulb.be

Advisor: Adam CHAFAI adam.chafai@ulb.be

Lab: TIPs

Description:

Context: Percipio Robotics is a spin-off from the FEMTO-ST research institute, which has designed the Tulip gripper [1]. This compact, lightweight gripper, weighing less than 30g, is designed for micromanipulation and can grip objects from 50µm to 10mm. It solves the problems of large grippers and fragility frequently encountered in micro-robotics. Parallely, the TIPs department designs and manufactures compliant mechanisms in glass (FemtoPRINT technique), whose deformation is measured with optical/photonics techniques.

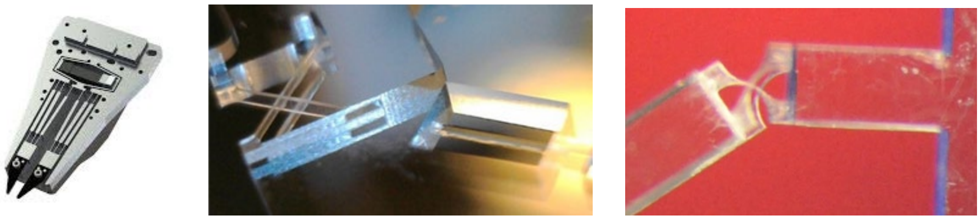

Figure (a) Tulip gripper; (b) Cross flex pivot; (c) cross flex pivot in bending

Objectives: This thesis aims to design and develop an instrumented version of the Percipio Robotics' Tulip gripper. The master thesis can be preceded by a 3 months internship in the company (Besançon, France).

Methods: Literature review. Functional analysis and requirements. Design. Fabrication and characterization of the flexure mechanism.

Prerequisites: mechanical design, good command of French

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References:

[1] https://ephj.ch/en/percipio-robotics-tulip-gripper-takes-micro-manipulation-to-the-next-level/

[2] L. Amez-Droz et Al. Instrumented Flexible Glass Structure: A Bragg Grating Inscribed with Femtosecond Laser Used as a Bending Sensor, MDPI Sensors, 23, 8018 (2023)

[3] M. Tunon de Lara, Femtosecond pulse laser-engineered glass flexible structures instrument-ed with an in-built Bragg grating sensor, Optics Express, https://opg.optica.org/oe/fulltext.cfm?uri=oe-31-18-29730&id=536683 (2023)

Plasmonic nanoparticles inside PNIPAM hydrogel for light-driven soft actuators using femtosecond laser writing

Supervisor Pierre LAMBERT pierre.lambert@ulb.be

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Description:

Context: Soft matter can serve as an actuator in microrobotics by deforming under external stimuli (light, heat, or pH…) and producing mechanical outputs like force or displacement. At the microscale, these smart materials can be 3D printed without assembly. In our lab, we use two-photon polymerization (2PP) to fabricate soft actuators from a thermo-responsive polymer, poly(N-isopropylacrylamide) (pNIPAM). This material swells below its lower critical solution temperature (LCST) by absorbing water and shrinks above the LCST by expelling it. Recently, we fabricated 50 µm × 50 µm × 50 µm active cubes capable of bending, contracting, twisting, or shearing in heated water [1]. To achieve precise, multidirectional motion control, multiple actuators could be combined and selectively triggered by different wavelengths of light. This is possible by doping them with photothermal nanomaterials that locally convert light into heat [2]. Metallic nanostructures like gold (Au) and silver (Ag) nanoparticles or nanorods have been used to actuate PNIPAM-based hydrogels [3]. However, they are usually dispersed uniformly, preventing spatial control. An alternative approach uses a tightly focused femtosecond laser in a PNIPAM hydrogel swollen with silver nitrate, locally forming Ag nanoparticles by multiphoton reduction [4]. Applying this method to our actuators would enable spatially selective nanoparticle patterning, allowing localized, precise activation.

Objective: The aim of this thesis is 3D print photosensitive nanoparticles inside PNIPAM hydrogels with the 2PP machine. After printing, light will be used to illuminate the actuators and will be converted into heat by the nanoparticles. The generated heat will trigger actuator motion by shrinking the hydrogel.

Methods: Literature review. Hydrogel fabrication (with 2PP printing). Printing of Ag/Au nanoparticles i.e., tune the printing parameters to obtain nanoparticles and optimize the actuation. Characterization: UV absorbance spectra, SEM imaging, and measuring the light responsiveness of the structures.

Prerequisites: Materials (to develop the fabrication process and understand the behavior of the hydrogels with and without nanoparticles).

References:

[1] Decroly, Gilles, Adam Chafaï, Guillaume de Timary, Gabriele Gandolfo, Alain Delchambre, et Pierre Lambert. 2023. « A Voxel-Based Approach for the Generation of Advanced Kinematics at the Microscale ». Advanced Intelligent Systems.

[2] Cui, Ximin, Qifeng Ruan, Xiaolu Zhuo, Xinyue Xia, Jingtian Hu, Runfang Fu, Yang Li, Jianfang Wang, et Hongxing Xu. 2023. « Photothermal Nanomaterials: A Powerful Light-to-Heat Converter ». Chemical Reviews 123 (11): 6891-6952.

[3] Park, Daehwan, Jin Woong Kim, et Chinedum O Osuji. 2024. « Programmable Thermo- and Light-Responsive Hydrogel Actuator Reinforced with Bacterial Cellulose ».

[4] Nishiyama, Hiroaki, Shun Odashima, et Suguru Asoh. 2020. « Femtosecond Laser Writing of Plasmonic Nanoparticles inside PNIPAM Microgels for Light-Driven 3D Soft Actuators ». Optics Express 28 (18): 26470-80.

Mechanical characterization of polymeric soft materials to be used as miniaturized actuators

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Description:

Context: Soft matter is used as an actuator in microrobotics. It can deform under an external stimulus (light, heat, or pH...) to generate a mechanical output (force and displacement). In the lab, we utilize the two-photon polymerization method (2PP) to shape 50µm soft actuators from a thermo-responsive polymer (pNIPAM = poly(N-isopropylacrylamide)). These active cubes demonstrate bending, contraction, twist, or shear deformation in a heated water bath [1]. Their mechanical performances must be characterized statically, to determine the elastic properties (Young modulus, Poisson coefficients) and/or dynamically, to determine the viscoelastic properties.

Objective: The aim of this thesis is to develop a setup to measure the force-displacement characteristics of such actuators. Inspired by Micro-Electro-Mechanical Systems (MEMS) force sensors [2] and/or atomic force microscopy (AFM) [3], this set-up will be fabricated in using glass microstructures (to be produced with the FemtoPrint machine) or with other materials deemed relevant by the candidate.

Methods: Literature review on characterizing the mechanical performance of soft material at microscale. Design the set-up considering the following criteria: 1) samples are characterized in water to allow them to swell and shrink, 2) a heating system (conventional or laser) will be used to drive the actuators, and 3) the sensor must be in contact with small samples (50 to 200 µm). Eventually, the results obtained may be supplemented and compared with data obtained with an environmental AFM, at UMons, and/or a nanoindentation system [4], at EMPA (Thun, Switzerland).

Prerequisites: Mechanics (to determine the device shape and develop the different part of the set-up using CAD software), coding (to automatically control the setup), and materials (to understand the material model obtained from experimental measurements).

References:

[1] G. Decroly, A. Chafaï, G. de Timary, G. Gandolfo, A. Delchambre, et P. Lambert, « A Voxel-Based Approach for the Generation of Advanced Kinematics at the Microscale », *Advanced Intelligent Systems*, 2023, doi: 10.1002/aisy.202200394.

[2] M. Lamba, N. Mittal, K. Singh, et H. Chaudhary, « Design analysis of polysilicon piezoresistors PDMS (Polydimethylsiloxane) microcantilever based MEMS Force sensor », *Int. J. Mod. Phys. B*, vol. 34, nº 09, p. 2050072, avr. 2020, doi: 10.1142/S0217979220500721.

[3] A. Chau, S. Régnier, A. Delchambre, et P. Lambert, « Theoretical and Experimental Study of the Influence of AFM Tip Geometry and Orientation on Capillary Force », *Journal of Adhesion Science and Technology*, vol. 24, nº 15-16, p. 2499-2510, janv. 2010, doi: 10.1163/016942410X508307.

[4] T. Spratte *et al.*, « Increasing the Efficiency of Thermoresponsive Actuation at the Microscale by Direct Laser Writing of pNIPAM », *Advanced Materials Technologies*, vol. 8, nº 1, p. 2200714, 2023, doi: 10.1002/admt.202200714.

Mechanical characterization of non-linear materials to be used as miniaturized actuators

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Description:

Context: Active soft matter can be used as an actuator in microrobotics. It can deform under an external stimulus such as light, heat, or pH to generate a mechanical output (force and displacement). At the microscale, these smart materials can be 3D printed without assembly. In the lab, we use the two-photon polymerization method (2PP) to shape 50µm soft actuators out of a thermo-responsive polymer (pNipam = poly(N-isopropylacrylamide)). These active cubes demonstrate bending, contraction, twist, or shear deformation in a heated water bath [1]. Their mechanical performances such as Young modulus, force-displacement characteristics, or response time must now be characterized.

Objective: The aim of this thesis is to use a setup to measure the force-displacement characteristics of such actuators and to analyze the indentation data with the help of a finite element approach to decouple the elastic parameters (Young modulus, Poisson coefficients) from the visco-elastic parameters.

Methods: Literature review on modeling soft material at microscale. Develop a code to analyze the experimental data. Eventually, the results obtained may be supplemented and compared with data obtained with an environmental AFM, at UMons, and/or a nanoindentation system [4], at EMPA (Thun, Switzerland).

Prerequisites: Numerical methods

References:

[1] G. Decroly, A. Chafaï, G. de Timary, G. Gandolfo, A. Delchambre, et P. Lambert, « A Voxel-Based Approach for the Generation of Advanced Kinematics at the Microscale », *Advanced Intelligent Systems*, 2023, doi: 10.1002/aisy.202200394.

[2] M. Lamba, N. Mittal, K. Singh, et H. Chaudhary, « Design analysis of polysilicon piezoresistors PDMS (Polydimethylsiloxane) microcantilever based MEMS Force sensor », *Int. J. Mod. Phys. B*, vol. 34, nº 09, p. 2050072, avr. 2020, doi: 10.1142/S0217979220500721.

[3] A. Chau, S. Régnier, A. Delchambre, et P. Lambert, « Theoretical and Experimental Study of the Influence of AFM Tip Geometry and Orientation on Capillary Force », *Journal of Adhesion Science and Technology*, vol. 24, nº 15-16, p. 2499-2510, janv. 2010, doi: 10.1163/016942410X508307.

[4] T. Spratte *et al.*, « Increasing the Efficiency of Thermoresponsive Actuation at the Microscale by Direct Laser Writing of pNIPAM », *Advanced Materials Technologies*, vol. 8, nº 1, p. 2200714, 2023, doi: 10.1002/admt.202200714.

Improved adenoid hypertrophy treatment through nasal replicas

Co-supervisors: Benoît HAUT, Pierre Lambert

Advisor: Clément RIGAUT

Lab: TIPs

Description:

Context: Adenoid hypertrophy is the pathologic enlargement of the tonsils at the back of the nose. It is one of the most common no-infectious ENT affection in children with a prevalence of about over 30%. Nowadays, the first-line treatment of adenoid hypertrophy is corticosteroid nasal sprays. While half of the patients shows improvement with this treatment, it is ineffective for the other half [1]. One issue may be that the current treatments aim for maximum coverage of the nasal cavity and not maximal penetration. Consequently, only a small part of the medicine reaches directly its site of action. New medication strategies, combining adapted devices, formulations and administration procedures [2], could increase the success of corticosteroid treatment and decrease the use of surgery in children.

Objective: This thesis aims to maximise the amount of drug reaching the pharyngeal tonsils. The fraction of drug reaching the site of action will be determined using a 3D-printed nasal replica of a child anatomy. The main goal is to combine the characteristics of the spray (viscosity, surface tension) and the administration procedure (instillation angle, inspiration) to increase the amount of drug reaching the back of the nasal cavity. Correlations between the characteristics of the sprays and the deposition in the nose should also be drawn to provide simple guidelines for future medicine development.

Prerequisites:

- Basic knowledge in fluid mechanics

Contact: Clément Rigaut (clement.rigaut@ulb.be)

References:

[1] Criscuoli, G. *et al.* Frequency of surgery among children who have adenotonsillar hypertrophy and improve after treatment with nasal beclomethasone. *Pediatrics* **111**, e236-238 (2003).

[2] Kundoor, V. & Dalby, R. N. Effect of formulation- and administration-related variables on deposition pattern of nasal spray pumps evaluated using a nasal cast. *Pharm Res* **28**, 1895–1904 (2011).

Development of a realistic and easy-to-use mucus simulant

Co-supervisors: Benoît HAUT, Pierre Lambert

Advisor: Clément RIGAUT

Lab: TIPs

Description:

Context: Over the last years, the respiratory drug delivery has drawn a strong interest due to the large surface area of the airway mucosa, providing an easy access to the blood. In particular, nasal sprays intending to treat non-local disorders, like migraine or hypoglycaemia, have appear. Compared to oral medicines, they are easier to use, act faster and can be given to unconscious patients [1]. However, the current characterisation techniques for spray are still lacking. Cutting-edge methods, such as experimental and digital models of the nose aims to bridge this gap but further development is still needed to reproduce adequately spray deposition in the nose. In particular, the interactions between the spray particles and the mucus lining the interior of the nose governs the final deposition site of the spray.

Objective: This thesis aims to develop a realistic and easy-to-use fluid replicating the nasal mucus. This simulant needs to reproduce the rheological characteristics of the biological mucus [2] and must be coated easily into nasal replicas. This mucus simulant will then be used to assess the influence of its properties (viscoelasticity, viscoplasticity, surface tension,…) on the trajectories of impacting particles. These results would strengthen the current understanding of the mucus-particles interactions and help to validate advanced simulation models.

Prerequisites:

- Rheology
- Classical mechanics

Contact: Clément Rigaut (clement.rigaut@ulb.be)

References:

[1] Kim, J. & De Jesus, O. Medication Routes of Administration. in *StatPearls* (StatPearls Publishing, Treasure Island (FL), 2023).

[2] Lafforgue, O., Seyssiecq, I., Poncet, S. & Favier, J. Rheological properties of synthetic mucus for airway clearance. *J Biomed Mater Res A* **106**, 386–396 (2018).

Variable stiffness catheter for lung cancer diagnosis

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Advisor: Margaux MANNNAERTS
Lab: TIPs
Description:

Context: Lung cancer is the leading cause of cancer death worldwide [1]. As part of the screening process, lung nodules (suspected cancer) are regularly found in peripheral areas that are difficult to access by endoscopy. As most of these nodules are not cancerous, it is essential to be able to take a local biopsy to make a precise diagnosis. However, the lung is like a labyrinth, with sections that shrink with each division, and access to a precise peripheral zone is difficult. In addition, the need to use flexible and miniaturized tools implies certain limitations. Indeed, the need for flexibility is necessary to avoid damaging the tissue or injuring the patient but means that the tools may deform before the biopsy is taken.

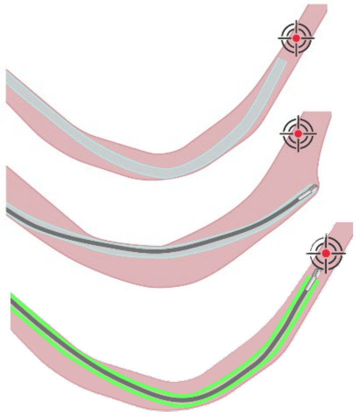

Figure 1 - Guide sheath is placed in front of a target (top), the guide sheath is deformed when a forceps is inserted (middle), the rigidification of the catheter locks it in the same place (bottom).

A family of solutions that are being developed uses the concept of controllable/variable stiffness to cope with these issues [2]. These solutions use materials and/or specific geometries that can change rigidity given a certain stimuli (change of temperature, pressure, …).

Objectives: Develop a prototype of a variable stiffness catheter using different equipment present in the lab (molding techniques, 3D printers).

Methods: Literature review. Functional analysis and requirements. Design. Fabrication and evaluation of the built prototype.

Prerequisites:

- Mechanical design
- Interest for mechanical and biomedical engineering

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References:

[1] Global Burden of Disease 2019 Cancer Collaboration *et al.*, « Cancer Incidence, Mortality, Years of Life Lost, Years Lived With Disability, and Disability-Adjusted Life Years for 29 Cancer Groups From 2010 to 2019: A Systematic Analysis for the Global Burden of Disease Study 2019 », *JAMA Oncol.*, vol. 8, nº 3, p. 420, mars 2022, doi: 10.1001/jamaoncol.2021.6987.

[2] L. Blanc, A. Delchambre, et P. Lambert, « Flexible Medical Devices: Review of Controllable Stiffness Solutions », *Actuators*, vol. 6, nº 3, p. 23, juill. 2017, doi: 10.3390/act6030023.

Biopsies in the periphery of the lung: shape sensing catheter tip

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Advisor: Margaux MANNNAERTS
Lab: TIPs

Description:

Context: Lung cancer is the leading cause of cancer death worldwide [1]. As part of the screening process, lung nodules (suspected cancer) are regularly found in peripheral areas that are difficult to access by endoscopy. As most of these nodules are not cancerous, it is essential to be able to take a local biopsy to make a precise diagnosis. However, the lung is like a labyrinth, with sections that shrink with each division, and access to a precise peripheral zone is difficult. In addition, the need to use flexible and miniaturised tools implies certain limitations. Indeed, the need for flexibility is necessary to avoid damaging the tissue or injuring the patient, but means that the tools may deform before the biopsy is taken. One way to ensure that the biopsy is taken at the right location is to have knowledge on the position and deformation of the catheter tip. Despite the exploration of various technologies such as electromagnetic sensors (EM), optical fibers, X-rays, etc [2], [3] , biopsy outcomes remain highly variable and dependent on a variety of factors including the type and number of used equipment, experience of the practician, location of the nodule in the lung. [4]

Objectives: This master thesis aims to design and develop a system enabling the practicians to know how the tip of the catheter is deformed in the lungs, due to their mechanical contact with the bronchii and the internal efforts developed in the catheter. Given the very small size of the peripheral bronchi (<1 mm), the system can be initially developed at a larger scale. Some inspiration can be taken from textile-based sensors, or other resistive strain gauges [5].

Methods: Literature review. Functional analysis and requirements. Design. Fabrication and characterization of a shape sensing catheter tip.

Prerequisites:

- Mechanical design, electronics
- Interest for mechanical and biomedical engineering

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References:

[1] J. M. Kocarnik et al., “Cancer Incidence, Mortality, Years of Life Lost, Years Lived With Disability, and Disability-Adjusted Life Years for 29 Cancer Groups From 2010 to 2019 A Systematic Analysis for the Global Burden of Disease Study 2019,” JAMA Oncol, vol. 8, no. 3, pp. 420–444, 2022, doi: 10.1001/jamaoncol.2021.6987.

[2] C. Shi et al., “Shape sensing techniques for continuum robots in minimally invasive surgery: A survey,” IEEE Trans Biomed Eng, vol. 64, no. 8, pp. 1665–1678, Aug. 2017, doi: 10.1109/TBME.2016.2622361.

[3] R. Brekken et al., “Accuracy of instrument tip position using fiber optic shape sensing for navigated bronchoscopy,” Med Eng Phys, vol. 125, Mar. 2024, doi: 10.1016/j.medengphy.2024.104116

[4] J. Thiboutot et al., “Accuracy of Pulmonary Nodule Sampling Using Robotic Assisted Bronchoscopy with Shape Sensing, Fluoroscopy, and Radial Endobronchial Ultrasound (The ACCURACY Study),” Respiration, vol. 101, no. 5, pp. 485–493, Mar. 2022, doi: 10.1159/000522514.

[5] S. Wu, « A n Overview of Hierarchical Design of Textile-Based Sensor in Wearable Electronics », *Crystals*, vol. 12, n° 4, p. 555, avr. 2022, doi: 10.3390/cryst12040555.

Bistable structures for bronchoscopy

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Description:

Context: Bistable structures enable multi-equilibrium states without the energy consumption except for switching from state to state. They are key in many applications, among which building engineering or soft robotics (https://www.non-linearity.com/conference/ftn2026). At small scale they could provide extra degrees-of-freedom to orientate and position endoscopic cameras such as the video-endoscope developed by Lys Medical.

Objectives: This master thesis aims to design and numerically model a bistable structure actuated by hydrogel actuators.

Methods: Literature review. Finite elements modelling (Batir). Design. Fabrication and characterization (Tips).

Prerequisites:

- Mechanical design
- Interest for civil, mechanical, biomedical and bio-engineering

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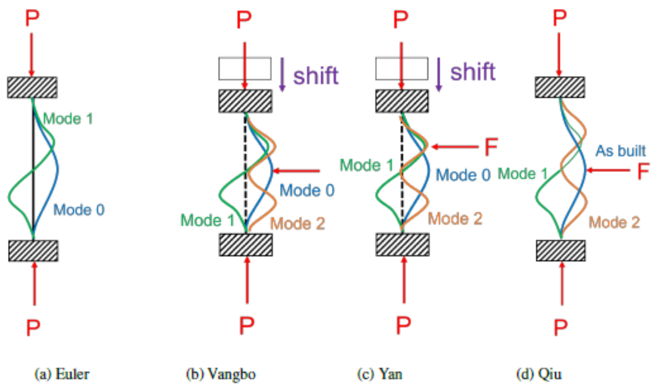

Figure 1: Different loading cases leading to beam buckling or beam bi-stability. (a) Historical beam buckling described by Euler (1757); (b) MEMS loading of a beam compressed by a axial shift (Vangbo, 1998), switching between states thanks to a vertically centered horizontal force; Loading similar to Vangbo, with a non vertically centered force *F* (Yan, 2019); (d) As-built precurved beam loaded by a vertically centered horizontal beam (Qiu, 2001)

References:

[1] Euler, L. (1759). Sur la force des colonnes. Memoires de l'academie des sciences de Berlin, 13:252–282. Euler archive.

[2] Vangbo, M. (1998). An analytical analysis of a compressed bistable buckled beam. Sensors and Actuators A, 69:212–216.

[3] Yan, W., Yu, Y., and Mehta, A. (2019). Analytical modeling for rapid design of bistable buckled beams. Theoretical and Applied Mechanics Letters, 9:264–272. 17

[4] Qiu, J., Lang, J. H., and Slocum, A. H. (2001). A centrally-clamped parallel-beam bistable mems mechanism. In Technical Digest. MEMS 2001. 14th IEEE International Conference on Micro Electro Mechanical Systems. IEEE.

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