ULB, TIPs department

Master Thesis and Internships

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

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

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<u>Lab:</u> TIPs

<u>Description:</u>

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.

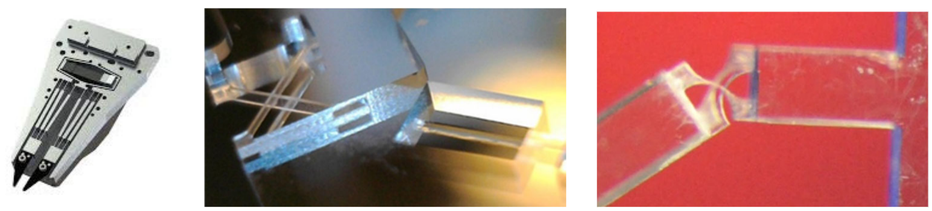

Figure (a) Tulip gripper; (b) Cross flex pivot; (c) cross flex pivot in bending

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 instrumented 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

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Description:

Context: Soft matter can serve as an actuator in microrobotics by deforming under external stimuli such as light, heat, or pH, 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 (from a silver nitrate solution) 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 or UV light). 2PP printing of Ag nanoparticles i.e., tune the printing parameters to obtain nanoparticles and optimize the actuation and mechanical properties, print complex deformation structures. Characterization: absorbance spectra, imaging the nanoparticles, 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 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 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. Select the most suitable device. 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.

Influence of the nasal anatomy on the air conditioning

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Description:
Context: The nose is responsible for heating and humidifying the air entering the respiratory tract. While it is only around 10 cm long, it can bring ambient air to a temperature of about 30°C in the pharynx. This function of conditioning the air before reaching the lower respiratory tract is vital to avoid inflammation, asthma and increased risk of infections. Despite the importance of this function of the nose, the heating of the air in the nasal cavity remains largely unknown.
Objective: This thesis aims to compute the temperature of the air exiting the nose under various conditions (rest, light effort, moderate effort,...) and ambient temperatures. The conditioning efficiency of different noses can be compared to deduce the influence of anatomical features on air conditioning.
Methods: First, the simulation models will be created from STL files of nasal cavities. Then simulations will be carried out using OpenFOAM software to measure the temperature of the air exiting the nose for various parameters. Finally, the results of the different anatomies will be compared to extract the anatomical characteristics impacting air conditioning.
Prerequisites:

- Fluid Dynamics
- Thermodynamics

Contact: Clément Rigaut (clement.rigaut@ulb.be)
References:
[1] D.-W. Kim, S.-K. Chung, et Y. Na, « Numerical study on the air conditioning characteristics of the human nasal cavity », Computers in Biology and Medicine, vol. 86, p. 18-30, juill. 2017, doi: 10.1016/j.compbiomed.2017.04.018.
[2] S. Naftali, M. Rosenfeld, M. Wolf, et D. Elad, « The Air-Conditioning Capacity of the Human Nose », Ann Biomed Eng, vol. 33, n° 4, p. 545-553, avr. 2005, doi: 10.1007/s10439-005-2513-4.

Individualized pharmacokinetics models to improve nasal delivery of neurological drugs

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Description:

Context: While nasal drugs have been widely used to treat local symptoms of colds or allergies, they have more recently emerged as a potential method for delivering neurological drugs. Indeed, the nose is highly vascularized, which ensures that molecules deposited in the nasal cavity will be readily absorbed into the bloodstream. Moreover, there is growing evidence that drugs can pass directly from the nose to the brain via the olfactory nerve [1]. However, a major drawback of nasal administration is its strong dependence on the individual's anatomy [2]. Therefore, personalized models are needed to predict the outcomes of nose-to-brain treatments.

Objective: This thesis aims to develop a pharmacokinetic model for the nasal administration of a neurological drug. The model will take into account the location of drug deposition (which varies between individuals), the transfer of the drug to the blood and brain, and its subsequent elimination. The goal is to determine the optimal treatment plan for each patient (e.g., one large dose or multiple smaller doses, liquid or dry spray, etc.) and predict the individual outcomes of these treatments.

Methods: Based on an extensive literature review, a pharmacokinetic model of the drug will be developed. Existing 3D-printed nasal replicas will be used to assess the distribution of the spray within the nasal cavity. These experimental data will allow for predictions of the treatment outcomes for a given anatomy and help identify the most suitable therapeutic approach for each individual.

Prerequisites:

- Knowledge of a programming language

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

References:

[1] L. Illum, 'Is nose-to-brain transport of drugs in man a reality?', Journal of Pharmacy and Pharmacology, vol. 56, no. 1, pp. 3–17, Jan. 2004, doi: 10.1211/0022357022539.

[2] C. Rigaut et al., 'What Are the Key Anatomical Features for the Success of Nose-to-Brain Delivery? A Study of Powder Deposition in 3D-Printed Nasal Casts', Pharmaceutics, vol. 15, no. 12, p. 2661, Nov. 2023, doi: 10.3390/pharmaceutics15122661.

Variable stiffness catheter for lung cancer diagnosis

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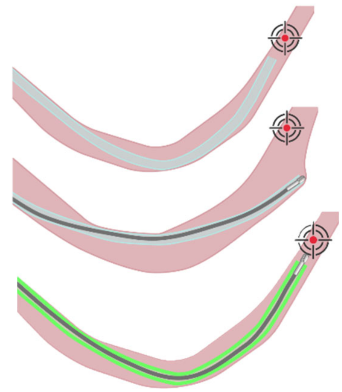

Figure 1 - Guide sheath is placed in front of a target (top), the guide sheath is deformed when a forceps is inserted (middle), the rigidification of the catheter locks it in the same place (bottom).

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.

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, n° 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, n° 3, p. 23, juill. 2017, doi: 10.3390/act6030023.

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

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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.