“4D” microprinted magnetic micro-robots for remote manipulation of cells

Roxane Pétrot

LANEF PhD Program 2019

My background

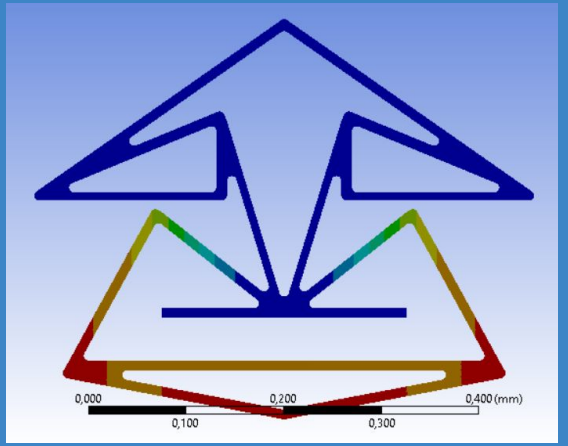
Education

Grenoble INP phelma • sept. 2016 - june 2018

- cell biology
- MRI, magnetism
- electronics, signal processing
- programming

Penn University of Pennsylvania • aug. 2018 - dec. 2018

- biomechanics
- mechanics of solids
- simulation



My background

Work and research

PETZL Blue-collar internship - 2017

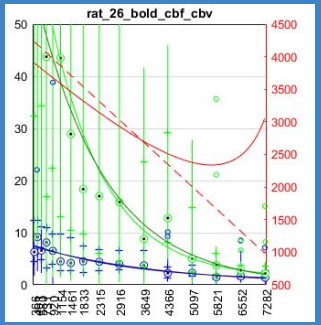
headlamp thermal stability testing:

- electronic circuit
- data acquisition
- data analysis

GIN M1R - 2018

fMRI data analysis:

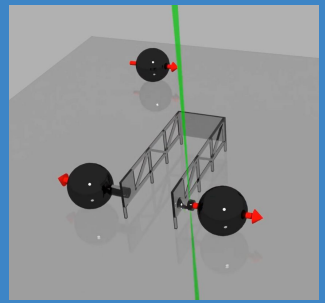
- analysis algorithms
- complex display
- MATLAB



G2Elab M2R - 2019

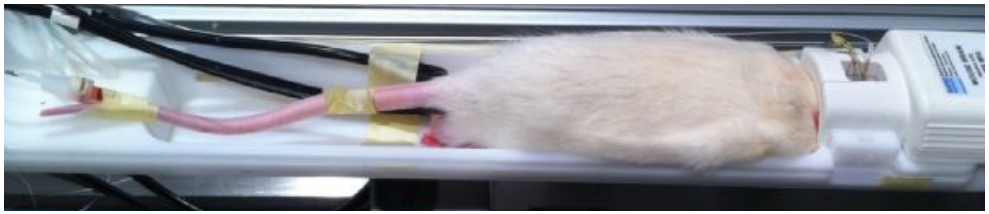
magnetic µ-robots:

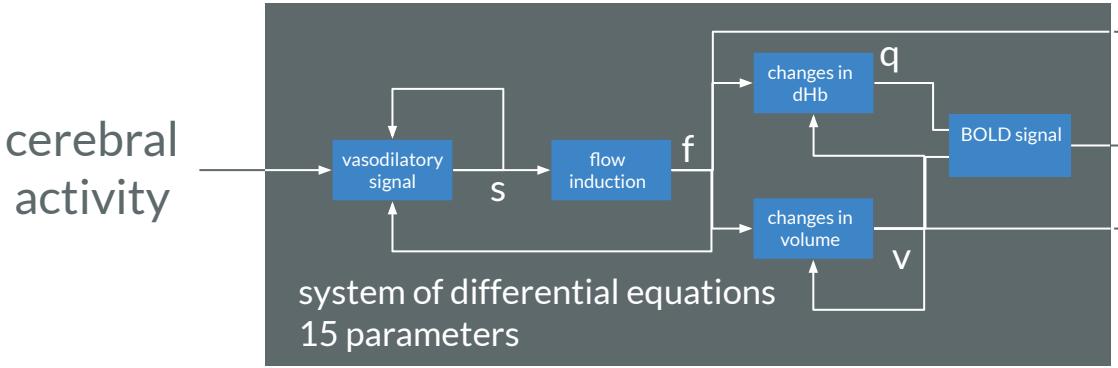
- design, simulation
- µ-fabrication
- article redaction

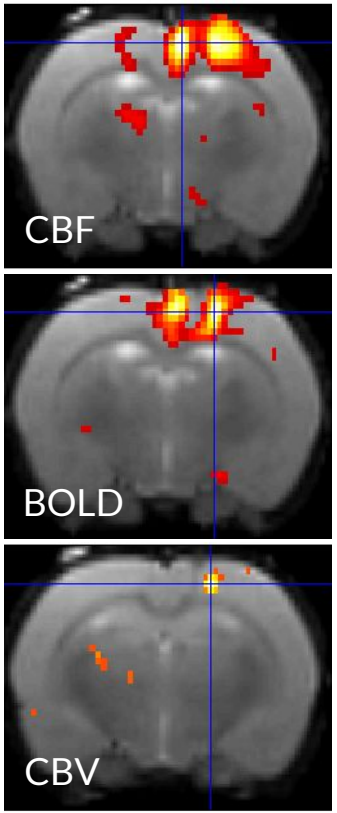


Scientific work - 1/2

Analysis of a biophysical model of multi-modal data obtained by functional MRI coupled to EEG

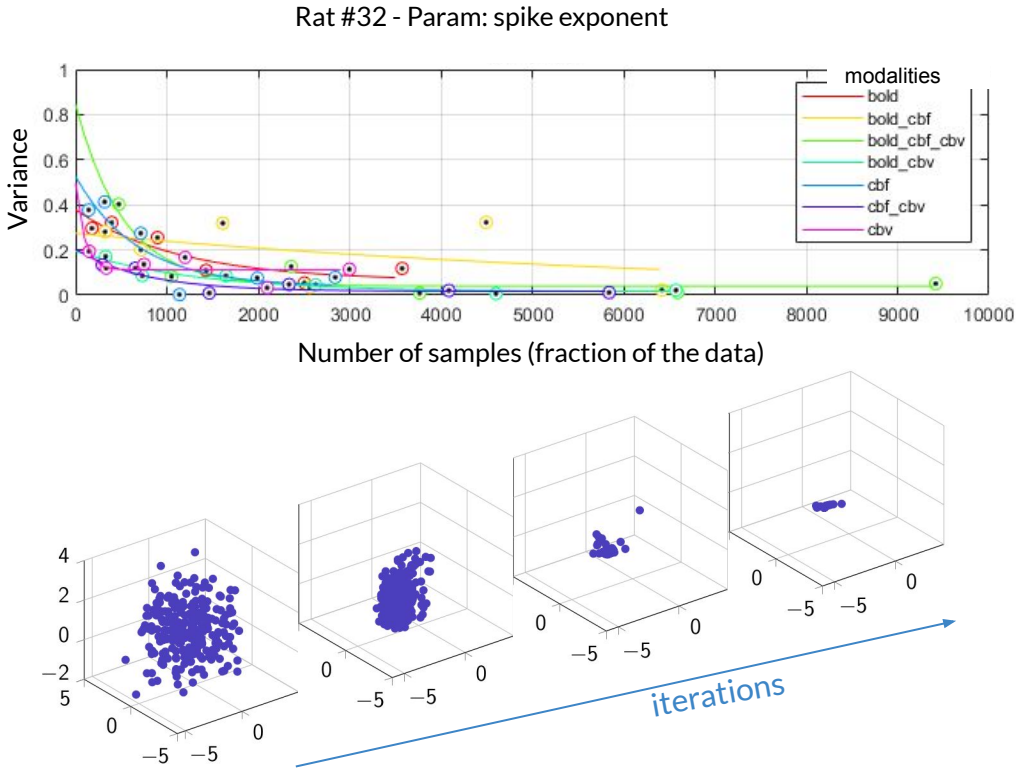






originality: literature/estimation → extraction from data

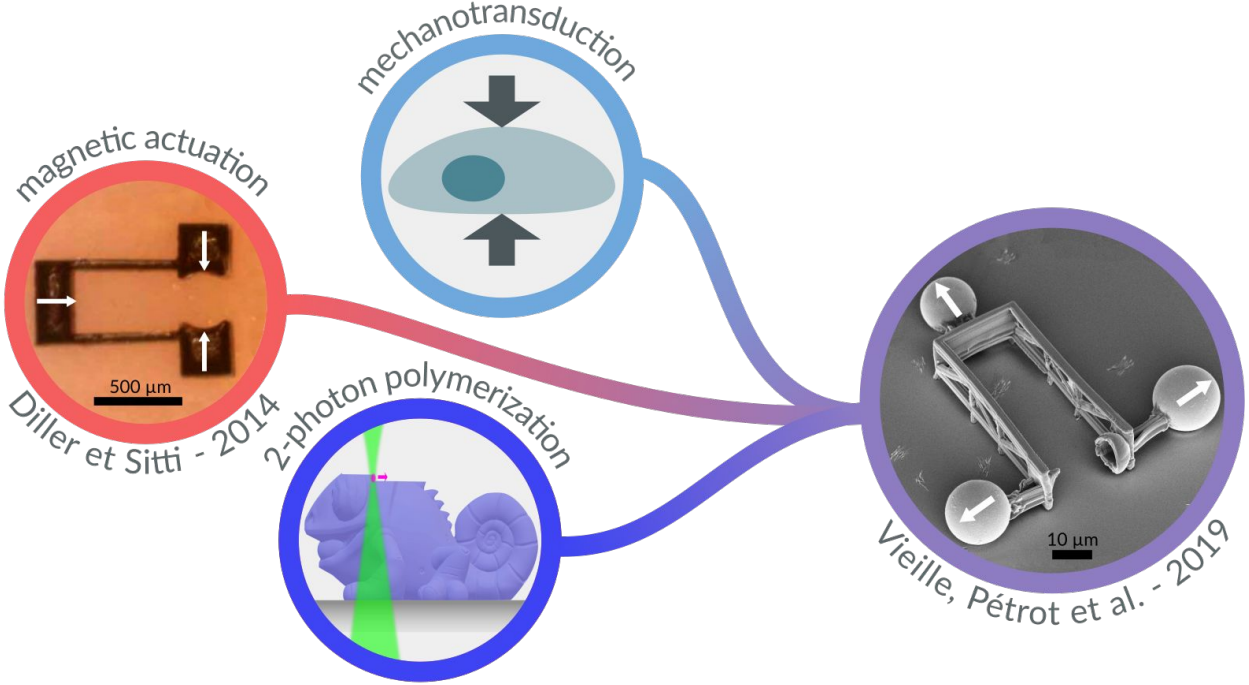
Scientific work - 2/2



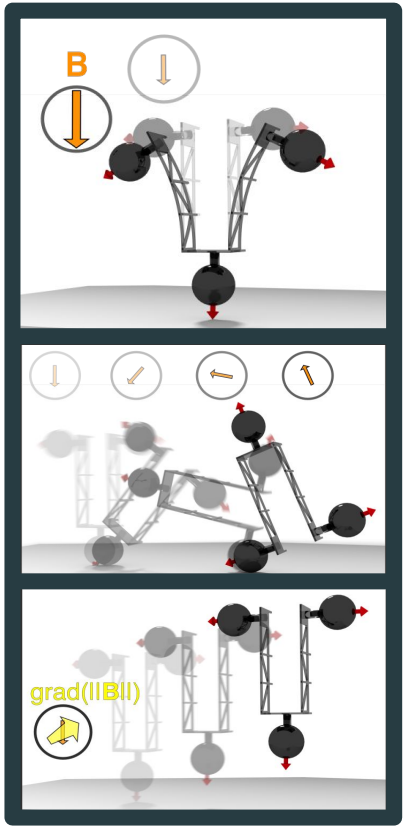
- Analysis of a big amount of data
- For each rat
  - fit 20 times on various fractions
  - plot uncertainty for each parameter as a function of the amount of data
  - compare between modalities
- Verify the results

Thesis project – 1/3

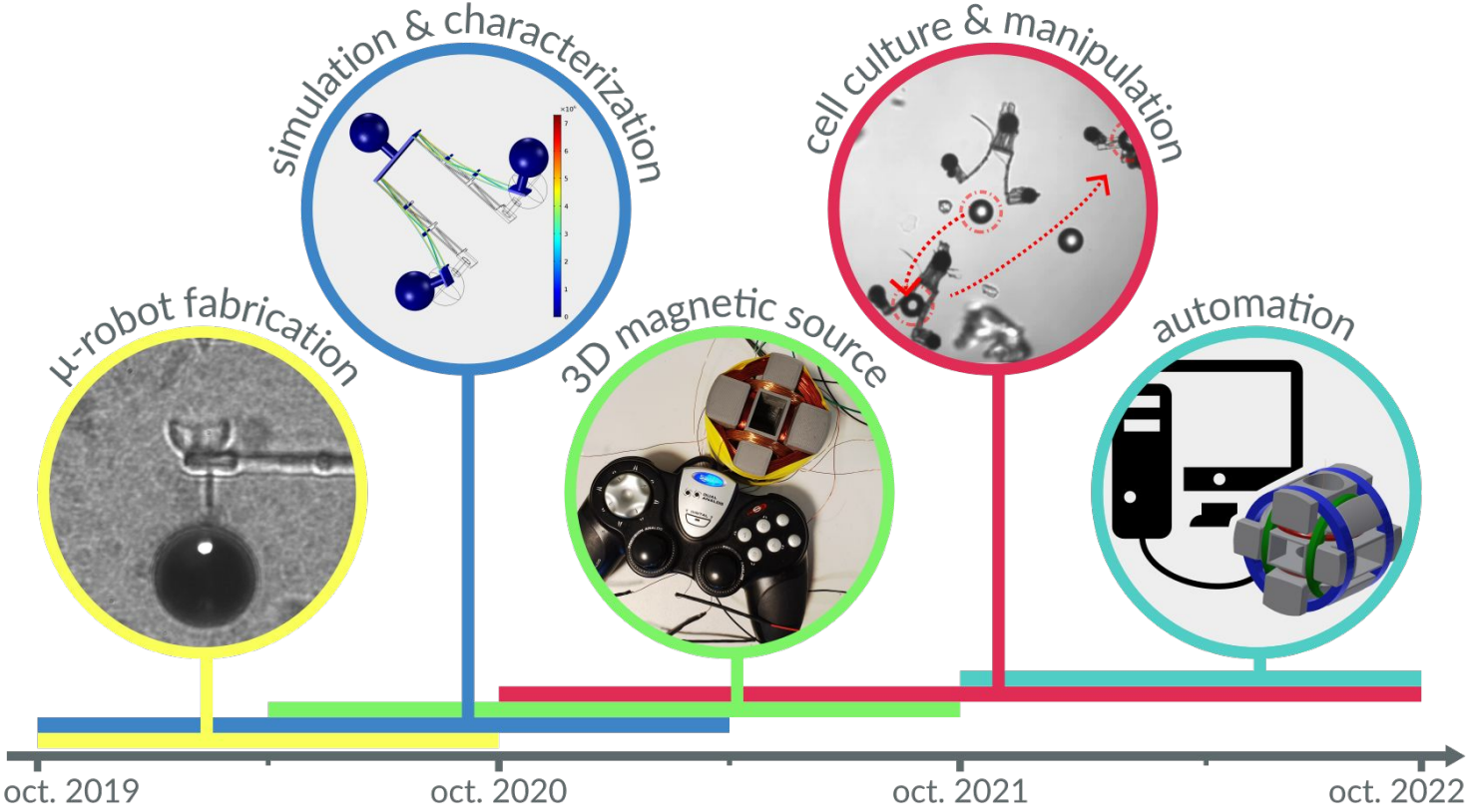
“4D” microprinted magnetic micro-robots for remote manipulation of cells



actuation modes



Thesis project - 2/3

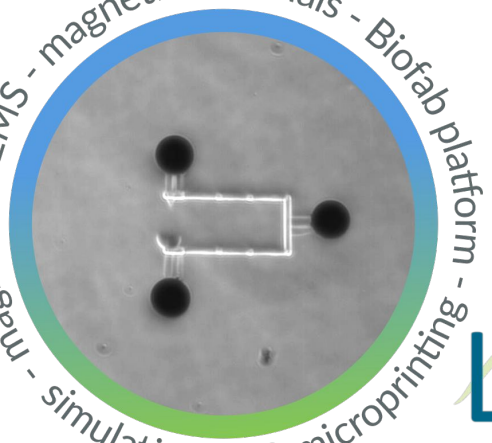


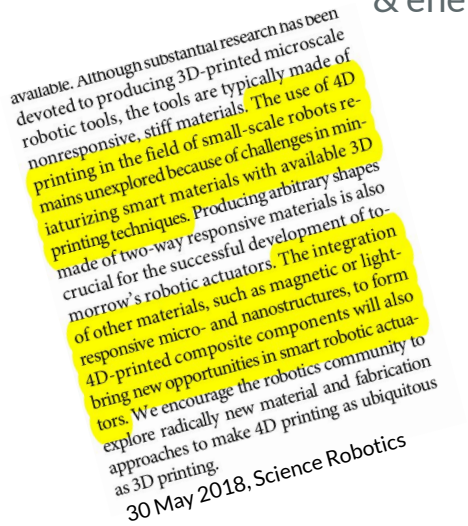
Thesis project – 3/3

Thibaut Devillers

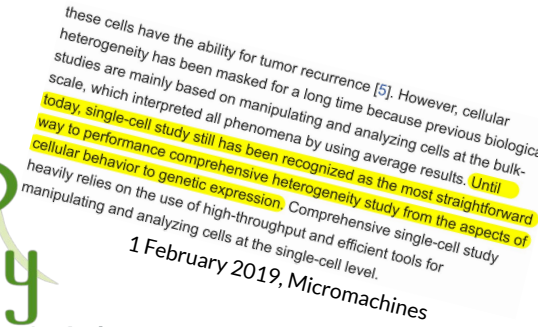
Mag-MEMS for med-tech & energy harvesting (25 years)

Magneto-active substrates for mechano-transduction (5 years)




available. Although substantial research has been devoted to producing 3D-printed microscale robotic tools, the tools are typically made of nonresponsive, stiff materials. The use of 4D printing in the field of small-scale robots remains unexplored because of challenges in miniaturizing smart materials with available 3D printing techniques. Producing arbitrary shapes made of two-way responsive materials is also crucial for the successful development of tomorrow's robotic actuators. The integration of other materials, such as magnetic or light-responsive micro- and nanostructures, to form 4D-printed composite components will also bring new opportunities in smart robotic actuators. We encourage the robotics community to explore radically new material and fabrication approaches to make 4D printing as ubiquitous as 3D printing.

30 May 2018, Science Robotics


these cells have the ability for tumor recurrence [5]. However, cellular heterogeneity has been masked for a long time because previous biological studies are mainly based on manipulating and analyzing cells at the bulk-scale, which interpreted all phenomena by using average results. Until today, single-cell study still has been recognized as the most straightforward way to performance comprehensive heterogeneity study from the aspects of cellular behavior to genetic expression. Comprehensive single-cell study heavily relies on the use of high-throughput and efficient tools for manipulating and analyzing cells at the single-cell level.

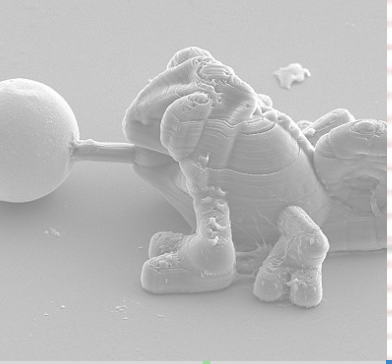
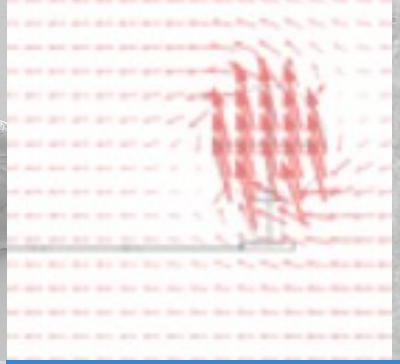
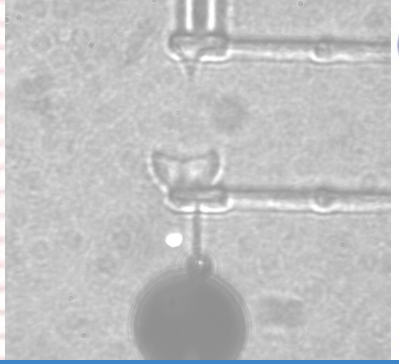
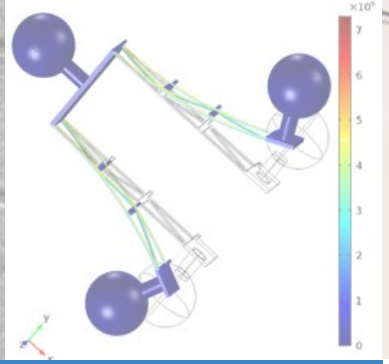
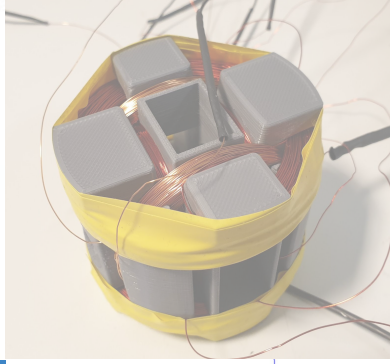
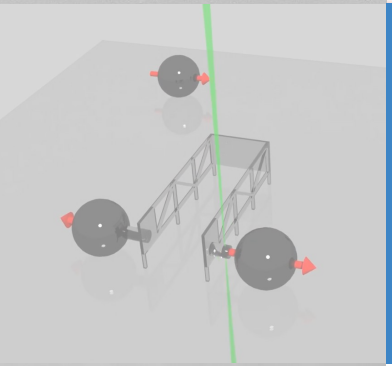
1 February 2019, Micromachines

G2Elab
Grenoble Génie Electrique
Grenoble Electrical Engineering

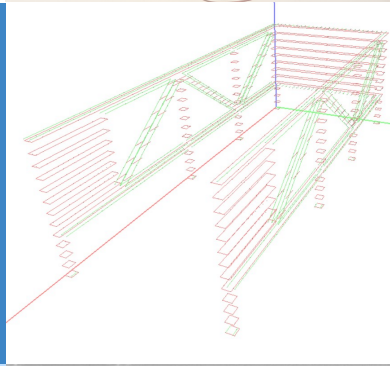
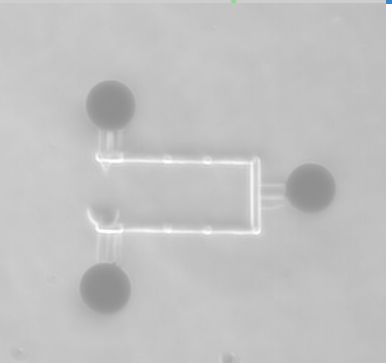
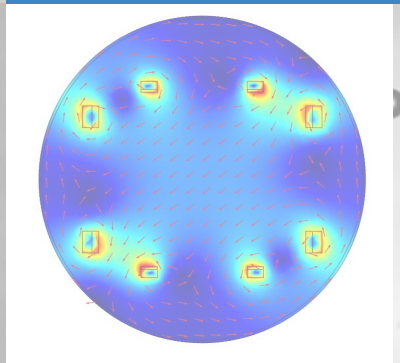
Orphée Cugat
PhD advisor

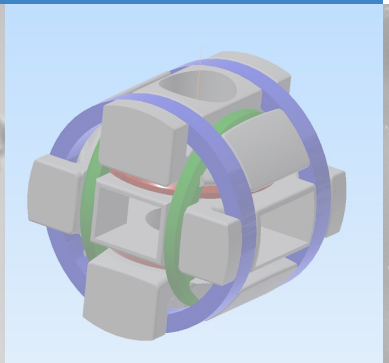
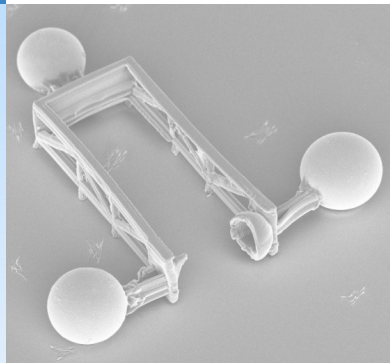
Olivier Stéphan

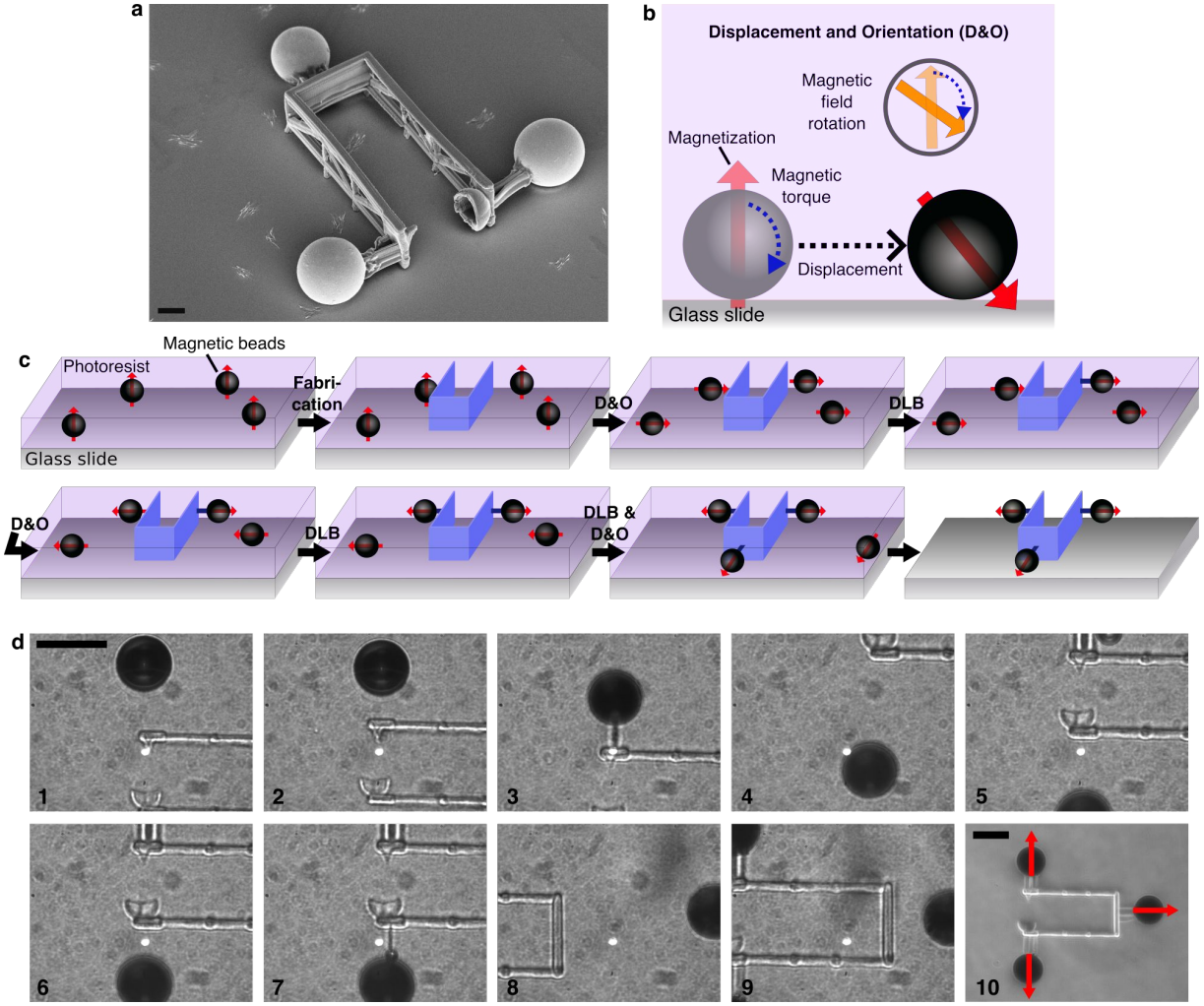
Magnetic µ-printed objects (2 years - PhD V. Vieille)

Thank you for your attention.

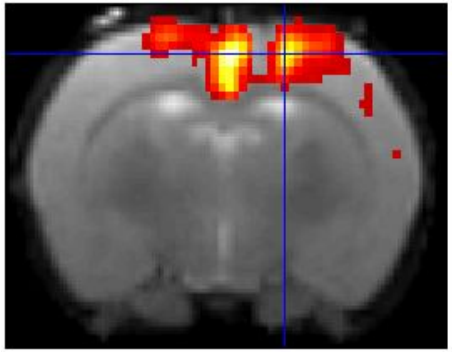





a
b
Displacement and Orientation (D&O)
Magnetic field rotation
Magnetization
Magnetic torque
Displacement
Glass slide
c
Magnetic beads
Photoresist
Fabri-cation
D&O
DLB
Glass slide
D&O
DLB
DLB & D&O
d
1
2
3
4
5
6
7
8
9
10

Scientific work - 1/2

Analysis of a biophysical model of multi-modal data obtained by functional MRI coupled to EEG



- models linking neural activity to fMRI signals
- fMRI & EEG data from 13 rats
- MATLAB code

context

scientific target

Better understand brain activity
→ develop models to link data from different neuroimaging modalities
→ study the influence of the parameters on the signals observed

- extract 15 parameter values combining 2 optimization methods
(usually taken from literature or estimated)

originality

expected outputs

Assess if there exists a clear link between physiological parameters and biophysical modelling of fMRI data

Thesis project – 1/3

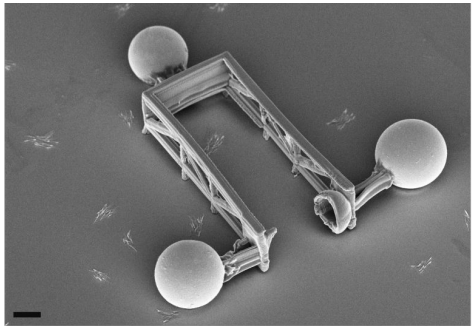
“4D” microprinted magnetic micro-robots for remote manipulation of cells

context

Mechanotransduction → understanding cell mechanical properties

scientific target

- remote-controlled, untethered µ-robots for manipulating cells in confined environments

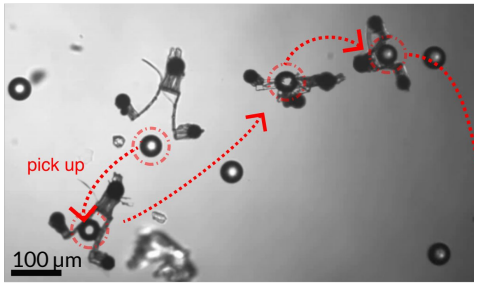


originality

Interdisciplinarity: µ-printing, magnetism, materials, biology, mechanics, control systems

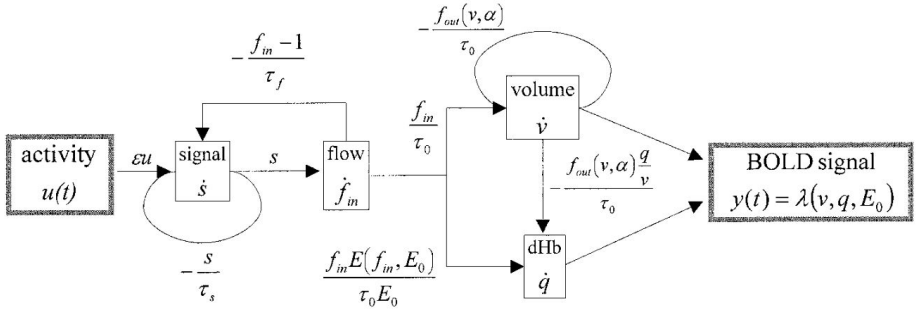
expected outputs

- design, build & operate a magnetic µ-robot at the scale of a cell
- use the µ-robot to stimulate cultured cells



The Balloon Model

Variable	Définition
u	Stimulation
f_{in}	Flux sanguin local
v	Volume de sang désoxygéné local
y	Signal BOLD

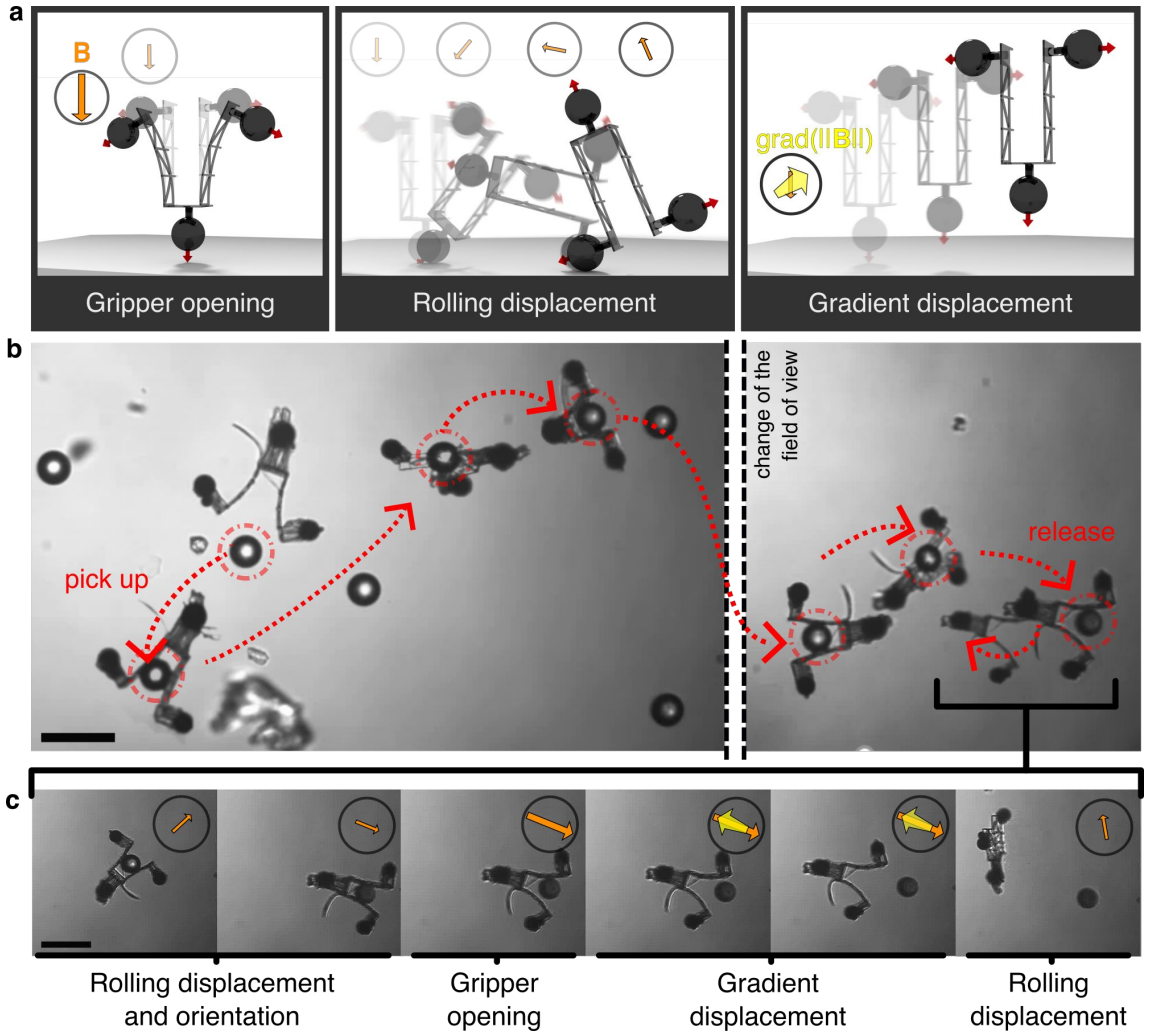


$\theta = \{A; B; C; D; E; se; sd; ar; tt; \alpha; \varepsilon; E_0; V_0; F_0; amplCBV\}$

$$\begin{cases} \dfrac{dn_e}{dt} = -E n_e - \exp\left(A + Bu^{se} + D^T \begin{pmatrix} n_e \\ s \\ f_{in} - 1 \end{pmatrix}\right) n_i + Cu^{se} \\ \dfrac{dn_i}{dt} = n_e - 2E n_i \\ \dfrac{ds}{dt} = n_e - sd\ s - ar\,(f_{in} - 1) \\ \dfrac{d\ ln(f_{in})}{dt} = \dfrac{s}{f_{in}} \\ \dfrac{d\ ln(v)}{dt} = \dfrac{1}{tt}\dfrac{f_{in} - v^{\frac{1}{\alpha}}}{v} \\ \dfrac{d\ ln(q)}{dt} = \dfrac{1}{tt}\left(\dfrac{1 - (1 - E_0)^{\frac{1}{f_{in}}}}{E_0}\dfrac{f_{in}}{q} - v^{\frac{1}{\alpha} - 1}\right) \end{cases}$$

$$y(t) = V_0[k_1(1 - q(t)) + k_2\left(1 - \frac{q(t)}{v(t)}\right) + k_3(1 - v(t))]$$

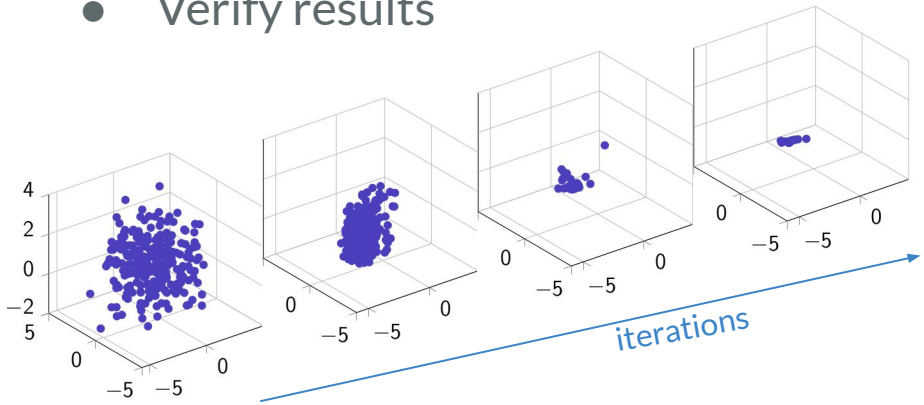
$k_1 = 4{,}3\,\theta_0 E_0 TE$, $k_2 = \varepsilon r_0 E_0 TE$, $k_3 = 1 - \varepsilon$

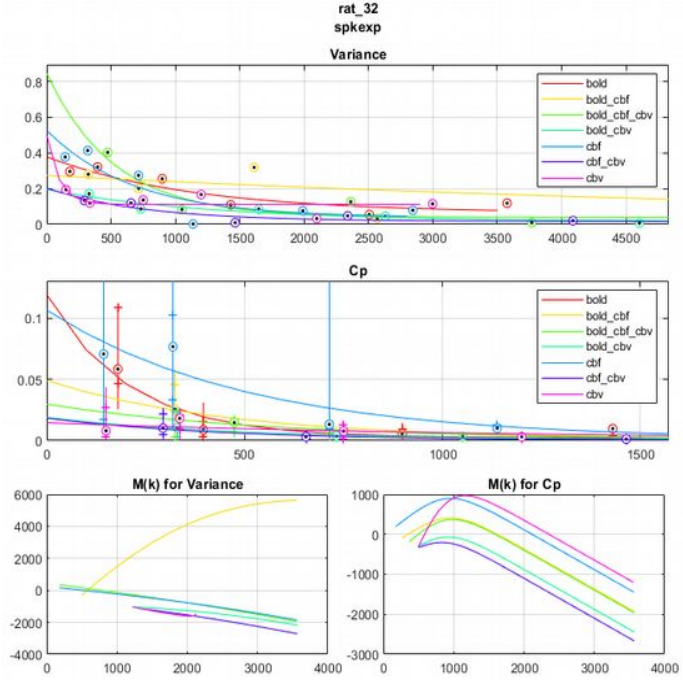

a
B
grad(||B||)
Gripper opening
Rolling displacement
Gradient displacement
b
pick up
change of the field of view
release
c
Rolling displacement and orientation
Gripper opening
Gradient displacement
Rolling displacement

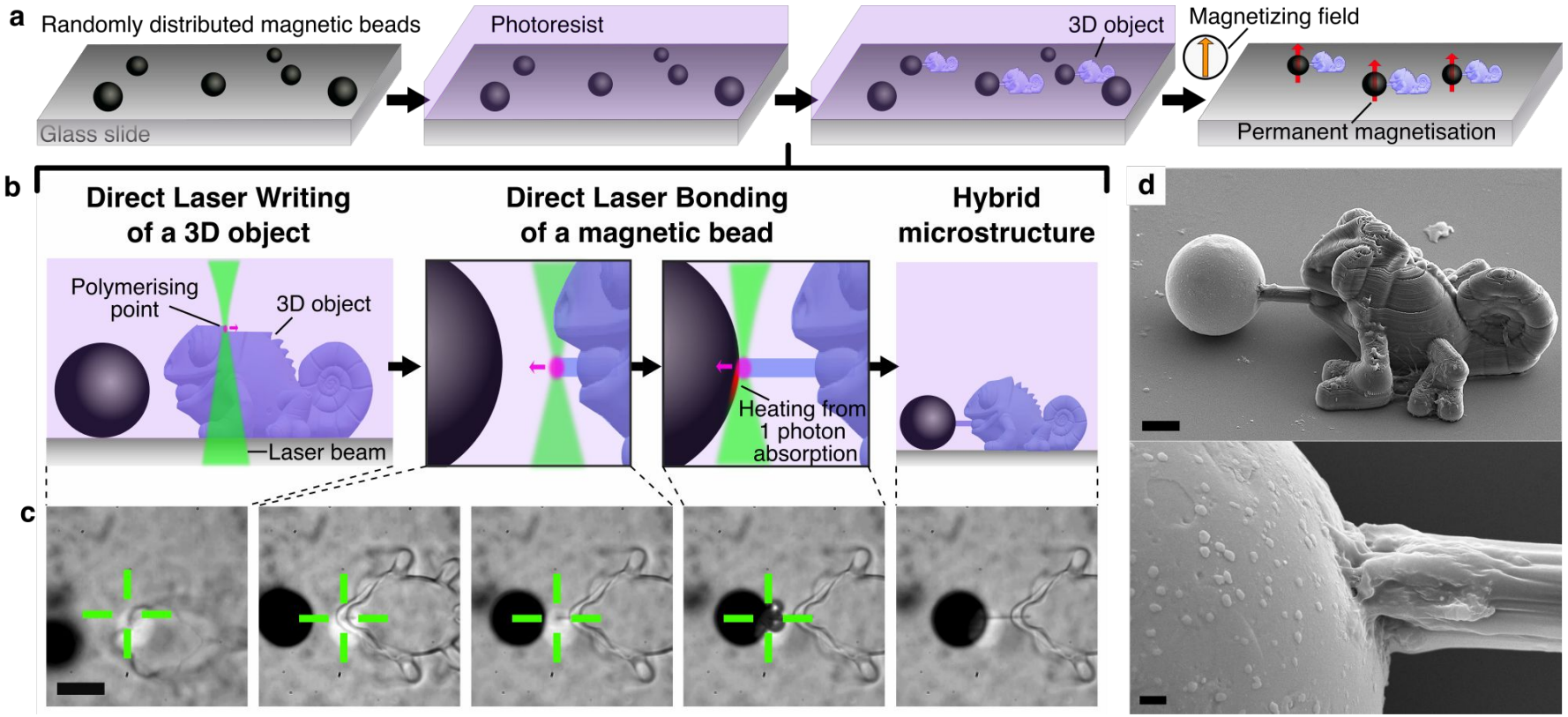
Scientific work - 2/2

my role

- Add and alter functions
  - Analyse data from fit
  - Display results
- Deal with the large amount of data
- Assess data informativeness
- Choose measure of uncertainty
- Verify results






a
Randomly distributed magnetic beads
Glass slide
Photoresist
3D object
Magnetizing field
Permanent magnetisation
b
Direct Laser Writing of a 3D object
Direct Laser Bonding of a magnetic bead
Hybrid microstructure
Polymerising point
3D object
Laser beam
Heating from 1 photon absorption
c
d

MANUFACTURING

4D printing and robotics

Carmela de Marco, Salvador Pané, Bradley J. Nelson*

Shape-memory materials and two- or three-dimensional printing techniques combine to form a new paradigm that will advance robotics.

Review

Microfluidic Single-Cell Manipulation and Analysis: Methods and Applications

Tao Luo [1,†], Lei Fan [1,†], Rong Zhu [2] and Dong Sun [1,3,*]