Master 2 Internship: Vision-Based Force Estimation on Deformable Micro-Structures Using a Digital Twin

Context:

In micro-robotics, measuring interaction forces is essential for manipulating and testing fragile objects (fibers, cells, compliant micro-mechanisms). However, conventional force sensors can be bulky, expensive and difficult to integrate at the microscale. An attractive alternative is to use deformation itself as a sensing principle: by observing structural deformation with a camera and combining it with a mechanical model, applied forces can be estimated without an integrated force sensor.

Current approaches, however, usually rely on simple stiffness models and on the tracking of a few points, which limits them to simple geometries and linear behavior. Combining full-field deformation measurement by vision with a digital twin of the structure, a numerical model fast enough to be updated in real time, opens the way to accurate force estimation on structures with complex geometry and nonlinear behavior (Fig. 1).

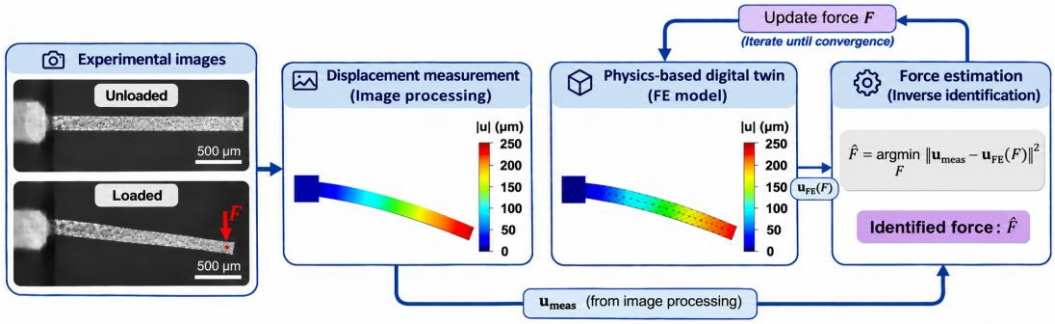


Fig. 1: principle of vision-based force estimation using a digital twin.

Internship objectives:

The main objective is to develop and experimentally validate a vision-based force estimation method for deformable micro-structures, combining image-based displacement measurements with a computational digital twin. The method will first be investigated under quasi-static, single-axis loading on a structure of known geometry, with the possibility of extending it to more complex configurations and real-time applications.

The selected candidate will be expected to:

1. Conduct a literature review on vision-based force sensing, deformation measurement (digital image correlation, feature tracking, etc.), and digital twins of deformable structures.
2. Measure the deformation by vision: implement a full-field displacement measurement techniques such as (KAZE/AKAZE feature-based tracking, or digital image correlation) and quantify their accuracy and spatial resolution and computation time.
3. Develop the digital twin: build a finite element model of the structure, identify its parameters from experiments and, depending on project progress, derive a reduced-order or learning-based surrogate model compatible with real-time use
4. Estimate the force: formulate and solve an inverse mechanical problem to estimate the applied force by matching image-based displacement measurements with model predictions. Quantify estimation uncertainty and sensitivity to measurement noise.
5. Validate experimentally: compare the estimated forces with a reference force sensor on a dedicated experimental setup, and evaluate accuracy, robustness to image noise and real-time performance.

Profile:

Master 2 or final-year engineering student in robotics, mechatronics or mechanics. Skills in image processing (OpenCV), solid mechanics and finite element modelling, and programming (Python and/or MATLAB); notions of estimation or optimization and first experience in machine learning are a plus; taste for experimental work and teamwork.

Additional information:

- **Laboratory:** FEMTO-ST Institute – AS2M Department – RoMoCo Team, Besançon
- **Project:** MINIRO (Miniature Robotics), French PEPR Robotics program funded by France 2030-https://www.femto-st.fr/en/The-institute/news/national-research-program-miniature-robotics
- **Duration:** 5 to 6 months, starting February 2027 – **Stipend:** 550 € per month
- **Application:** CV, cover letter and transcripts of the last three years, in a single PDF
- **Supervisors:**
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  - Cédric CLÉVY cedric.clevy@femto-st.fr