UNIVERSITÉ MARIE & LOUIS PASTEUR

RÉGION BOURGOGNE FRANCHE COMTÉ

cnrs

école doctorale **sciences physiques** pour l'**ingénieur** et **microtechniques** SPIM

Titre de la these / Thesis title: Study of robot calibration strategies for 6-axis micromanipulators using distributed or onboard microforce sensors.

Laboratoire d'Accueil / Host laboratory: FEMTO-ST Institute, AS2M Department

Spécialité du doctorat préparé / Specialty : Robotics.

Mots-clefs / Keywords: Robotics calibration, kinematic calibration, micro-force sensors, real-time force control, on-board force sensing, distributed force sensing, measurement fusion.

Context of the thesis:

The AS2M department at the FEMTO-ST Institute, which specializes in microrobotics and micro-mechatronics, has been conducting research for over 20 years on the design, modeling, fabrication, and control of microsystems and microrobots. In this time, our laboratory has made strides in finding innovative ways to improve the precision and repeatability of micromanipulation systems for different applications (Figure 1) [1][2]. However, the objective to create a generalized calibration method adaptable for all micromanipulation robotic structures to have sub-micrometric precision on a workspace of tens of centimeters has not yet been possible given the constraints of the micro-scale. Indeed, at this scale, mechanical backlash, changes in geometric parameters depending on the workspace and environmental conditions, as well as the relative flexibility of the joints (particularly for microforce measurement applications) are significant factors that must be taken into account if we wish to achieve a multi-degree-of-freedom robotic system capable of positioning itself and performing rotations with sub-micrometer precision over a large workspace.

However, it is possible to draw inspiration from classical robotics to explore methods applicable to microrobotics. Certain applications, such as robotic machining [3] and robot-forming [4] (robotic sheet metal forming), use kinematic models that account for the stiffness of the robot and that of its individual joints (including clearances) as distributed fixed parameters and configuration-dependent parameters. These methods are combined with on-board force measurements to perform machining operations, resulting in an accuracy on the order of tens of micrometers, using robots weighing hundreds of kilograms with working ranges of several meters [5].

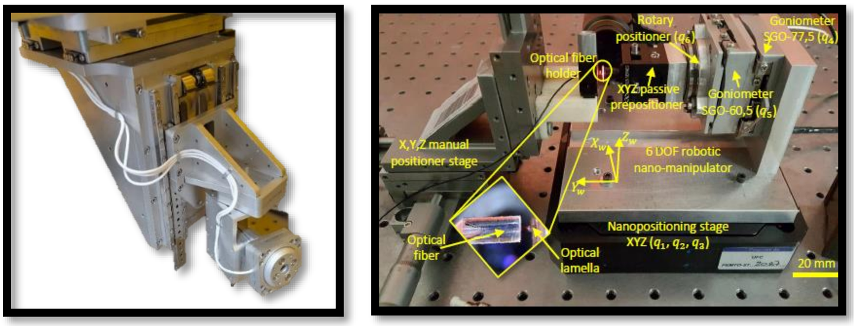

Figure 1 : To the left, 6 DOF micromanipulator robot of the µRobotex platform. To the right, the 6-DOF Nanoroboptic platform [2]. Both are part of the Center of Micro and Nano Robotics (CMNR) experimental platform at FEMTO-ST, Besançon, France.

Therefore, in the absence of tools equivalent to on-board cameras [6] or absolute reference systems (laser trackers) [7] often used for the calibration of large scale robots, we believe that the use micro-force sensors could serve as the bridge that would bring macroscopic techniques from industrial robotics into the field of microrobotics. Indeed, micro-force sensors, when combined with microscopy techniques, currently enable micromanipulation systems to perform probing operations allowing them to close kinematic chains for the purposes of calibration procedures [8][9]. However, in these studies, micro-force sensors were only used to ensure a given sensor/sample distance or as binary contact/no-contact detectors, so the resulting calibrations were purely geometrical in nature. Hence, there is an exciting potential in exploiting fully the capabilities of micro-force sensors to compensate for mechanical, static, dynamic, and environmental sources of error.

Objective of thesis

With this context in mind, the objective of this thesis is to develop generalized protocols for calibrating robotic micromanipulators, based on the use of microforce sensors together with joint encoders. The proposed strategies shall integrate micro-force sensors as an **exteroceptive measurement** technology, which is to measure forces that are external to the robot (**palpation**). The force measurement can either be done using on-board micro-force sensors or by scattering multiple sensors around the robot's workspace. It would also be possible to use indirect proprioceptive measurements (robot joint measurements) synthesized using **observers**. All these measures shall be fused together in a coherent matter to correct the **static** robotic model of the micro-manipulator and to develop **dynamic control strategies** to reach precise contact positions for the calibration procedure and obtain a **submicrometric** level of precision. The microforce sensors used for this purpose may be based on one of many different measurement technologies used for micromanipulation [10], such as **piezoelectric sensors** (tuning-fork AFM probes) [8][9] and **MEMS**, either based on **piezoresistive force sensing** [11] or capacitive measurement and comb-drive actuation [12]. Furthermore, these sensors may also be based on the actuation and measurement of the deformation of **flexible/articulated structures remote-controlled via optical fibers** [13].

The final goal of developing such procedures is on the one hand, **to significantly improve the precision for the positioning and rotational control** of these systems, and on the other hand, to improve the **accuracy of microforce measurements using micromanipulators regardless of the direction of the force or the robot's configuration**. The fulfilment of the latter is of particular importance, so that the procedure can be used in various applications such as the characterization of mechanical properties of microstructures under different loading conditions like compression, tension and shear forces. [14][15]

Figure 2 : To the left, Piezo-resistive force sensing microgrippers [11]. At the center, an articulated micro-gripper actuated by an optical fiber [13]. To the right, a force sensitive micro-gripper testing the mechanical properties of a granular material [15]

Multiple steps will be examined to develop a viable robot calibration protocol:

- Study of the measurement principle: what type of technology should be used for the sensors which could be onboard or scattered/distributed throughout the station.
- Development of a robotic contact strategy (with static and/or dynamic control of the magnitude and direction of applied forces i.e. based on dynamic hybrid force-position control) that ensures reproducible interactions with the station and the robot's working environment, to obtain the data required for the calibration method.
- Measurement campaigns to analyze the sensitivity of the robot's accuracy to robot configuration parameters as well as environmental factors.
- Proposal for a configuration-dependent calibration method that accounts for variability of stiffness (robot, environment, sensor).

By the end of the thesis, the objective is for the micromanipulator robots studied to be able to control the position and rotation of their working tool along the three axes (X, Y, and Z) with sub-micrometer precision within a large working envelope following calibration. Ideally, this envelope will have a volume of several hundred cubic centimeters. Additionally, the robot must be able to utilize its entire working envelope for the precise measurement of microforces in all directions.

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Environnement de travail / The PhD position and working environment:

The PhD thesis work contract is expected to start in October 2026 for a 3 year duration. The PhD candidate will be a full member of the Department of Automation and Micro-Mechatronic Systems (AS2M) at the FEMTO-ST Institute in Besançon, France. FEMTO-ST is a research institute internationally renowned for its expertise in micromanipulation, miniature robotics, flexible robotics, advanced automation, optics and applied mechanics. The PhD candidate will be part of the ROMOCO team (Robotics, Modeling and Control) of AS2M and will have close collaboration with engineers and researchers, notably within the CMNR (Centre de Micro et de Nano Robotique) and will have full access to the MIMENTO platform if required (platform part of the national Renatech network). The candidate will be encouraged to participate in current ongoing national and international collaborations or to initiate one if so desired. The PhD student will have access to all equipment part of the TIRREX platform on micro-nanorobotics (national network of robotic platforms of excellence) located in the AS2M department. The PhD student will also be a full member of the PEPR MINIRO, which is a new national project to deploy "miniature robotics" through a network of excellence comprising the 9 research institutes contributing to this field. This is a very fruitful working environment that will allow the PhD student to develop their project and research through a collaborative network at a national and international level.

Profil demandé / Qualifications:

We are seeking a highly motivated candidate who is a team player with an open mind and results oriented. The candidates are expected to have the following skills:

- Candidates with a MSc or equivalent degree (engineering degree or master's degree) specializing in robotics, mechatronics or a related field, covering both methodological/theoretical and experimental aspects.

- Skills in robotic calibration, dynamic control, kinematic and mechanical modeling of robots, along with a strong track record in experimental work, are essential.
- Skills in Matlab/Simulink programming, particularly for creating real-time applications and for automation, are highly desirable.
- Candidates must be fluent in English. French would be an advantage but not necessary.

Livrables / Deliverables:

Several deliverables will be expected from the PhD thesis this will be the form of:

- The writing of reports: to formalize research advancements regularly, a yearly thesis report as well as the thesis manuscript,
- The dissemination of the works/results: by publishing in international journals in robotics and mechatronics, by attending international conferences and workshops at the international, national and regional levels and by presenting the thesis/research thematics during visits, and
- The sharing of experience with people in the group.

Financement / Contract:

The contract will be for a duration of 3 years, and it will be fully funded i.e. will enable full-time research. The contract will be established by the UMLP "Université Marie et Louis Pasteur." The salary (gross) will be about 2300€/month.
Additional teaching activities can be available in case of interest. Note that registrations fees at the university (about 400€/y) and medical costs are very low in France as it is a national social security system.

Application:

Please submit to any of contacts below your CV, a cover letter, and your transcript from your master's program or engineering degree in a single PDF. If you have significant work experience (more than one year, excluding internships), you may submit a document (no more than two pages) detailing aspects of your professional background that you believe are relevant to your application.

Application deadline:

As soon as possible, the selection process is ongoing and will last until the position is filled.

Direction de these / Thesis supervisor:

Prof. Cédric CLEVY, cedric.clevy@femto-st.fr.

Encadrement de thèse / Thesis co-director /co-encadrant:

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