SPECI-MeN Group
Sensing strategies, Perception and Characterization at Micro- and Nano-scales

AS2M Dep – Automatic Control and Micro-Mechatronic Systems
AS2M dep multi-disciplinary research fields:

- Automatic control,
- Robotics,
- Mechatronics,
- Industrial engineering.

AS2M dep research axes:

- Micro-robotics (micro-manipulation & assembly, characterization and biomedical appl.),
- Control of systems at the micro-scale (micro-robots, micro-actuators, micro-systems),
- Prognostics & Health Management (industrial and biological systems).

AS2M dep research groups:

SPECIMeN, CODE, MiNaRoB, PHM.

SPECIMeN group framework:

Study, development and use of specific sensing devices and information processing methods to optimize the implementation and the performances of “perception – decision – action” loops operating at micro- and nano-scales.
SPECIMeN scientific issues and activities

Exploitation of sensors at micro-nano scales

Development of sensors for micro-nano scales

Research applications and projects scope

Head: Ass. Prof. E. Piat - 1 full prof., 2 ass. prof., 3 engineers
Development of sensors for micro-nano scales

Sensors design

- Micro-nanoforce sensors (mono & multi DOF, elastic & rigid, low & high inertia)
- Complete force sensing platform design

Sensors modeling and calibration, sensing quality estimation

- Multi-scales imaging (SEM)
- Micro-nanoforce sensors stiffness calibration
- S/N estimation (SEM, micro-nanoforce measurement)
- Fiber bundle based imaging calibration

Defects and disturbances characterization and correction

- Distortion (SEM)
- Global drift (SEM)
- Mechanical drift (nanoforce sensor with high inertia)
- Low frequency vibrations characterization and cancellation (nanoforce sensor with high inertia)
One DoF micro-nano-force sensor using diamagnetic levitation

Research framework

When high bandwidth in micro and nano force measurement is not mandatory, the use of rigid macroscopic force-displacement transducers is a possible alternative to force sensors based on elastic microstructures. Sensors using such transducer are easy to produce using conventional assembly approaches and also easy to handle thanks to the size of the transducer. The SPECIMeN group is developing such sensors characterized by high resolution and long range force measurement using passive stable magnetic springs resulting from the combination of attractive magnetic forces coupled with a repulsive physical principle (diamagnetic repulsion).

Sensor characteristics

Macroscopic force-displacement transducer: 10-cm long capillary tube (20 to 80 mg).
Force measurement: along the capillary longitudinal axis.
Adjustable stiffness: 0.005 N/m to 0.03 N/m.
Resolution: 1 to 5 nN (1)
Max range: ± 50 µN typ. (2)
Displacement bandwidth: 4 Hz typ. (3)
Max force bandwidth: 15 Hz typ. (1)
Displacement measurement: confocal chromatic sensors.
Response: under-damped second-order linear force-displacement dynamic.

(1) depends on the S/N ratio wanted on force measurements and the resolution of the displacement sensor.
(2) depends on the range measurement of the displacement sensor used.
(3) depends on the mass of the capillary tube.


Contact: emmanuel.piat@ens2m.fr, joel.abadie@femto-st.fr
Three DoF micro-nano-force sensor using magnetic springs and upthrust buoyancy

Research framework

When high bandwidth in micro and nano force measurement is not mandatory, the use of rigid macroscopic force-displacement transducers is a possible alternative to force sensors based on elastic microstructures. Sensors using such transducer are easy to produce using conventional assembly approaches and also easy to handle thanks to the size of the transducer. The SPECIMeN group is developing such sensors characterized by high resolution and long range force measurement using passive stable magnetic springs resulting from the combination of attractive magnetic forces coupled with a repulsive physical principle (upthrust buoyancy).

Sensor characteristics

Macroscopic force-displacement transducer: floating platform (4 g).
Force measurement: $F_x$ and $F_y$ horizontal components
Torque measurement: $C_z$ vertical component
Stiffness: 0.02 N/m.
Resolution: 10 to 20 nN \(^{(1)}\)
Max range: ± 20 µN typ. \(^{(2)}\)
Displacement bandwidth: 1 Hz typ. \(^{(3)}\)
Max force bandwidth: 10 Hz typ. \(^{(1)}\)
Displacement measurement: confocal chromatic sensors.
Response: under-damped second-order linear force-displacement dynamic.

\(^{(1)}\) depends on the S/N ratio wanted on force measurements and the resolution of the displacement sensor.
\(^{(2)}\) depends on the range measurement of the displacement sensor used.
\(^{(3)}\) depends on the mass of the capillary tube.


Contact: emmanuel.piat@ens2m.fr, joel.abadie@femto-st.fr
Piezoresistive multi-DoF micro-force sensor for multi-asperity friction characterization

Research framework

Dedicated Microtools for reliable measurements of plane-plane or sphere-plane multi-asperity friction forces and torques with 6 DoF do not exist to date. But such friction conditions are the most common conditions encountered during the successive steps of micro-manipulation or assembly. Thus they should be studied to achieve a better reliability during these operations. One way to make friction characterization in the micro-robotics framework consists in developing new dedicated and multi-DoF microforce sensors for this particular purpose.

A silicon micro-fabricated force sensor based on piezoresistive effect with multi-degree-of-freedom measurement capabilities is currently under development. The main fabrication processes are: lithography, PECVD, RIE, DRIE, sputtering and evaporation metal deposition, fully proceeded at MIMENTO in FEMTO-ST at Besançon. Preliminary results show a dynamic friction coefficient around 0.2 for Si3N4 600µm sphere on <111> Silicon plane in good appropriateness with the measurements done with a CSM Nanotribometer used by Stemplié and Al (femto-st MN2S dept).

Main sensor characteristics

Principle: compliant 6-DoF elastic structure with piezoresistive strain gages
Force measurement: \( F_z \) (normal force) and \( F_{x,y} \) (tangential force)
Stiffness: \( F_{x,y} : \approx 800 \text{ N/m} ; F_z : \approx 1500 \text{ N/m} \).
Expected resolution: \( x,y < 1 \mu\text{N} ; z : \approx 1 \mu\text{N} \).
Max range: \( F_{x,y} : 0.1 \text{ to } 10 \text{ mN}; F_z : 1 \text{ to } 100 \text{ mN} \).
First resonance frequency: \( x,y,z > 6000 \text{ Hz} \).

(1) depend on the design and dimensions of the sensor.

Major article: work in progress!

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AFM-based robotics platform for micro-force measurement and mechanical characterization

Research framework

Microhandling performed with robotics devices is a promising way to assemble microcomponents. The success in complex tasks achievement for micro–nano robotics is conditioned by the analysis of surface effects. However, at the scale of several micrometers, adhesion phenomenon highly perturbs micro-objects release and final positioning. This phenomenon is directly linked to both the object and the gripper surface mechanical and chemical properties. The control of the adhesion properties requires multidisciplinary approaches including roughness control, mechanical properties control and chemical surface functionalization.

Skills associated to the NANOROL platform

The applicative objective of the AFM-based NANOROL robotics platform is to improve the reliability of micro-objects manipulation which necessitate to control the different contact or non-contact forces involved in the dynamic of such micro-objects. Interactions have been studied between a micrometric sphere and a plane. The study of the deformation of an AFM beam whose end is equipped with a tip or a sphere allows the characterization of functionalized or patterned substrates that are used on the fingers of micro-grippers developed at AS2M. The measurements can be made in dry or ambient environment, and also in wet environment whose pH can be modified to control the adhesion / repulsion forces.


Contact: patrick.rougeot@femto-st.fr
Multimodal robotics platform for micro-force measurement and mechanical characterization

Research framework
The adhesion between a micro-nano-object and a micro-gripper end-effector is an important problem in micromanipulation. Cancellation or reduction of this force is a great challenge. The evaluation of plane-plane contact force has become a big issue in micro/nano micro-assembly. Reliable experimental equipments are needed to validate research works done on plane-plane interactions (theoretical formulations or virtual simulations with finite elements).

Multimodal platform characteristic
A micro-force sensor probe tip (either Femtotools sensor or AFM cantilever) associated to a piezoelectric nano-translator and a precision parallel robot are used to obtain an integrated robotics system. This system is currently used for micro-force measurement induced by a plane-plane contact.

In the proposed system, the two micro-objects whose mechanical interaction needs to be characterized are fixed on the parallel robot end-platform and on the micro-force sensor probe tip respectively. This high precision robotics system is used to provide six degrees-of-freedom motion between both objects. So this platform is convenient for the measurement of micro-forces occurring between planar objects with different orientations.

As a significant application, the proposed system is used for the measurement of pull-off force between planar objects. In the future, it will also be used to measure friction forces in the context of multi-asperity nano-tribology.


Contact: patrick.rougeot@femto-st.fr
SNR calculation of the nanoforce estimation obtained by the deconvolution of the noisy output of a force-displacement transducer

Research framework

In micro and nano force measurement using rigid macroscopic force-displacement transducers connected to magnetic springs, the under-damped and long transient response due to the transducers mass inertia can not be neglected for time-varying force measurement. It is thus necessary to deconvolve the transducer noisy output displacement measurement to correctly estimate the unknown input force, which leads to a trade-off between the SNR of the estimation and the bandwidth of the force sensor.

Proposed approach

The deconvolution approach implemented is based on a discrete Kalman filter with an uncertain a priori model to represent the unknown micro-nano force to be estimated. This model is a discretized Wiener process including a $W_F$ parameter which is a power spectral density whose value has to be adjusted by the end-user.

The $W_F$ parameter makes possible the adjustment of the trade-off between the SNR of the nano-force estimation (view as the ratio mean / standard deviation of the estimation) and the force sensor bandwidth (correlated to the response time of the estimation).

The $W_F$ parameter can be modified at any time by the end-user to adjust the estimation quality. The SNR (or simply the standard deviation of the estimation which is directly correlated to the force resolution) and the frequency response versus $W_F$ can be pre-computed and plotted in order to make this choice easier.


Contact: emmanuel.piat@ens2m.fr
SEM image quality monitoring based on single image real-time SNR estimation

Research framework

It is a well-known fact that scanning electron microscopic (SEM) image acquisition is mainly affected by nonlinearities and instabilities of the column and probe-specimen interaction. These phenomena lead to unstable quality images. For optimal use, in automatic mode, of these images it is necessary to monitor their quality. This work focuses on this monitoring through the computation of the signal-to-noise ratio (SNR) which is a commonly used measure in the field of signal processing to estimate the strength of a signal with respect to the background noise.

Proposed approach

So far, two images of the same specimen area have been used in many research works to compute the signal-to-noise ratio based on cross-correlation technique. The disadvantages associated with these methods are that they require the two images to be perfectly aligned, and a long processing time. Alternative methods have used a single image to compute the SNR based on the simple approximation and first-order extrapolation of cross-correlation. Even though the results are good enough, these methods are highly dependent on the nature of images and are not suitable for real-time use.

In this work, assuming the level of noise is high, and the presence of drift in imaging process, we overcome above difficulties by developing a simple and robust noise estimation method based on non-linear filtering and then computing the SNR using a single image. In turn, it is used to monitor the SNR of a scanning electron microscope images to estimate image quality during micro-nano structure manipulation and characterization tasks.


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Image distortion compensation in scanning electron microscope using a non-parametric model

Research framework

As optical microscopes, the scanning electron microscopes can deliver images affected by pixel distortions. Generally, the level of distortion is inversely proportional to the magnification. The distortion of a pixel comprises a radial component and a tangential component. Distortions compensation is a very important action if one want to use SEM images to make accurate measurements in the whole image area. For this purpose the polynomial model of the distortion is usually considered. This leads to iterative and long calibration methods. For the scanning electron microscope images, this work explores an alternative solution.

Proposed approach

In this work, a non-polynomial model of radial and tangential components of the distortion is considered. It includes a distortion center (a priori different from the principal point), a parameter of radial distortion and a parameter of tangential distortion.

Initially the center of distortion is estimated by neglecting the tangential distortion. It is obtained from the fundamental matrix reflecting the geometric constraint between the calibration grid points and their images. In a second step, both radial and tangential parameters are taken into account and calculated using a bundle adjustment.

The concepts were successfully applied to images providing from a scanning electron microscope with a tungsten filament for magnifications ranging from 100x and 10 kx (JEOL-JSM 820).


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Fast image drift compensation in scanning electron microscope using image registration

Research framework

It is a well-known fact that scanning electron microscopic (SEM) image acquisition is mainly affected by nonlinearities and instabilities of the column and probe-specimen interaction; in turn, producing a shift in the image points with respect to many parameters and time, in particular. The compensation of this phenomenon is an important issue if one wants to use a SEM for measurements involved in material characterization or for complex micro-nano-robotics tasks.

Proposed approach

In these works, image registration-based drift compensation methods have been developed. The homography between the reference image and the current one is computed using two approaches.

- In the first approach, phase correlation of the pair of images is used to compute the homography between both images.

- In the second approach, keypoint detection and matching are used to compute the homography between the pair of images. Four algorithms have been tested: SURF, FAST, ORB and dense matching.

The results of all methods are consistent: the images tested show no rotation or shear, or scaling. However, ORB detector provides the best compromise between accuracy of drift compensation and computation time.