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

AS2M Dep⁴ – Automatic Control and Micro-Mechatronic Systems
AS2M dep² multi-disciplinary research fields:
- Automatic control,
- Robotics,
- Mechatronics,
- Industrial engineering.

AS2M dep² 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 dep² 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
Multi-scale sensing strategies

- Trade-off adjustment between resolution / range measurement / bandwidth
- 3D reconstruction with low depth of field vision
- Tracking and multi-scale 2D and 3D visual servoing for tasks automation
- Visual servoing in SEM using global visual features for auto-adaptative imaging: 
  autofocusing, autoscaling, positioning, scanning autosynchronization.
- High speed vision for nanorobotics (SEM)

Mechanical characterization of micro / nano objects and interfaces

- Estimation of microstructures elastic properties
- Estimation of human oocytes non-stationary elastic properties
- Estimation of static and dynamic friction coefficients for multi-asperity contacts
- Characterization of functionalized or patterned substrates (adhesion forces and non-contact forces)
Trade-off adjustment between resolution and bandwidth in low frequency force measurement with magnetic springs

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 displacement to correctly estimate the unknown input force, which leads to a trade-off between the resolution 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 parameter which is a power spectral density whose value has to be adjusted by the end-user.

The main advantage of this approach is that the end-user can directly control with this parameter the unavoidable trade-off that exists between the wished resolution on the estimated force (aka its standard deviation) and the force sensor bandwidth (correlated to the response time of the estimation).

This approach is computationally cheap and makes possible the extension of the sensor bandwidth beyond the low natural resonant frequency of the macroscopic force-displacement transducer (up to x3 extension possible with low noise displacement sensors). It also takes into account the dynamic behavior imposed by the mass inertia.

3D reconstruction of surfaces from the analysis of image sharpness

Research framework

The main property of microscopes (optical as well as electronic) is the relative weakness of their depth of field: about 3 microns for a 10X optical microscope, about 5 microns for a 1000X scanning electron microscope (SEM). This makes difficult the use of microscopes to image 3D-dynamic scenes with large depth of view involved in micro-nanorobotics tasks.

Conversely, this property can be used to perform 3D-reconstruction of scene surfaces. Indeed, low depth of field causes a high sensitivity of image sharpness to the relative position of the microscope with scene: sharpness codes on this position and can be used to determine it.

Proposed approach

The main stages of the developed method are:

• Acquiring a set of images with respect to the working distance,
• Cleaning of images to remove outliers,
• Calculating sharpness of each pixel using the appropriate function,
• Detecting, for each pixel column, of the pixel outputting the maximum sharpness,
• Filtering of 3D points obtained.

Major article: Naresh Marturi, Sounkalo Dembélé and Nadine Piat. Depth and shape estimation from focus in scanning electron microscope, IEEE Int. Conf. on Control, Automation, Robotics & Embedded Systems (CARE) 2013, Dec 16-18, India.
Visual Servoing for Advanced Micro Assembly

Research framework
This work focuses on the combination of 2D and 3D visual servoings for automatic performing of micro assembly applications. Structures targeted measure 400±1.5µm x 400±1.5µm x 100±1.5µm and must be inserted in their grooves of 100±1.5µm x 100±1.5µm x 100±1.5µm. The mechanical play varies between 0 and 3 µm. The corresponding setup comprises a large number of resources: a carrier for structures (xyα robot), a carrier for the gripper (zφ robot), a 2-fingers gripper, a computer controlled zoom vertical microscope and a lateral microscope. Assembly sequences include a large number of tasks: gripping, release, displacement, gripper opening, gripper closing, zooming in, zooming out, ... The visual servoings to implement require a level of precision consistent with the mechanical play, and a high level of robustness.

Proposed approach
The critical tasks of structures gripping and release have been assigned to a specific resource (vertical microscope, 2D visual servoing) because of the high level of precision of 2D visual servoing. Tracking the 2D position of keypoints (the four corners of the visible face) is performed using the ESM algorithm from Malis. The displacement tasks were assigned to another specific resources (lateral microscope, 3D visual servoing) because of the level of robustness of the 3D visual servoing. Tracking the 3D position of each structure is achieved using ViSP. In both cases (2D and 3D visual servoings), the control law is the exponential decrease of the error between the current and desired positions.

These principles have been applied successfully, thus showing their relevance for microstructures assembling at this particular scale.


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Efficient Autofocusing in Scanning Electron Microscope using Visual Servoing

Research framework
Fast and reliable autofocusing methods are essential for performing automatic nano positioning tasks using a scanning electron microscope (SEM). So far in the literature, various autofocusing algorithms have been proposed utilizing a sharpness measure to compute the best focus. Most of them are based on iterative search approaches, applying the sharpness function over the total range of focus to find an image in-focus. As a result, the process is long. This work investigates alternative approaches based on visual servoing.

Proposed approach
In this work, new, fast and robust visual servoing-based autofocusing method for SEM is studied. Unlike the traditional methods, the developed method performs the focusing by regulating to zero a cost function (primary task). A secondary task is used to improve the primary task: it stops precisely the overall process, when the best focus position is reached. For this work, the normalized variance, a quadratic cost and the gradient of the sharpness score with respect to distance have been selected as sharpness score, primary task and secondary task, respectively. Obtained experimental results prove the fastness of the developed method over existing search-based approaches and its precision in finding the best focus. The proposed autofocusing approach has also been validated at different experimental conditions and the obtained results prove the robustness of the method.


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Human oocytes mechanical characterization with a robotics sensing platform based on magnetic springs

Research framework

The human oocytes selection plays a critical role in assisted reproductive technology (ART) success rate. In order to improve this rate, a new instrumentation is necessary to extend the usual ways used by physicians to determine oocytes quality and their maturity level. This new instrumentation must be compatible with ART constraints and physicians habits.

Among the new ways available to determine the maturity level of a human oocyte, the characterization of its mechanical properties is potentially interesting and has to be investigated. This study requires a force sensor with a very low stiffness (to have a high resolution) and also a large measurement range if high deformations have to be characterized. Force sensors based on magnetic springs have such characteristics and can potentially be a part of this new instrumentation.

Proposed approach

Experimental load-unload cycles have been applied on humans oocytes with a magnetic springs based robotics platform. The stiffness of the embedded 2-DOF force sensor is 0.02 N/m. The complex mechanical influence of the IVF culture medium is not negligible and has to be compensated with a specific experimental measurement protocol. The human oocytes elastic behavior is linear for low loading (around 0.01 N/m) and non-linear for high loading. After high loading a plastic behavior is associated to the unload stage. This behavior is oocyte dependant and a significant evolution in time has been observed for a given oocyte.


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Characterization of adhesion forces with functionalized polymer substrates

Research framework
During micro-assembly processes, contacts occur between micro assembling tools (like micro-gripper end-effectors) and the manipulated micro-object or between a substrate and a micro-object. The pull-off force, which represents the force required to break a contact, is one of the predominant problems in micro-assembly. This force is directly linked to the surface chemical structure of both the object and the assembling tool and depends on their interaction.

Proposed approach
The use of functionalized surfaces based on polymer electrodeposition leads to a significant reduction of the adhesion force that were demonstrated by pull-off force measurements. These measurements were performed with the NANOROL robotics platform specifically dedicated to micro-force measurements.

Gold and silicon surfaces were functionalized with 4 different Intrinsically Conducting Polymers (ICPs): polypyrrole, polyaniline, p-phenylenediamine and 3,4-polyethylenedioxythiophene deposited by electropolymerization. The polymer morphological features were also determined by AFM and Scanning Electron Microscopy (SEM) in the aim to correlate both polymer morphologies and polymer chemical structures with their adhesion properties.

Characterization of pH-controlled attraction / repulsion forces with functionalized substrates

Research framework

The adhesion that occurs between a micro-object and a micro-manipulation tool like the end-effectors of a micro-gripper is an important issue in micro-manipulation and micro-assembly. Adhesion forces cancellation or reduction in a controlled way is also a great challenge in micro-robotics. The adhesion force is directly linked to the surface chemical structure of both the object and the micro-tool and depends on their interaction. Based on the fact that electrostatic forces can generate a predominant effect on the micro-scale range when the micromanipulation occurs in a liquid medium, controlling the electrostatic forces should enable to control the attraction and repulsion behavior between surfaces during approach and retract stages.

Proposed approach

Electrochemical effects can be exploited in order to control electrostatic surface charge density via chemical equilibrium between the surface and the liquid medium. The principle used in this approach is based on the protonation of silica, which enables to switch from SiO\(_2\) to SiO\(^-\) according to the pH. The combination of both effects enables to obtain a surface whose electrostatic charges switch from a positive value for low pH to a negative value for high pH which makes possible the control of the adhesion force with the pH. Surface functionalization of both object and gripper can be obtained by different methods (physisorption, grafting...).

The pull-off force measurements were performed with the NANOROL robotics platform specifically dedicated to micro-force measurements. They were done on a functionalized plane using a micro-cantilever whose end was equipped with a sphere that was functionalized or not.

Characterization of sphere-sphere attraction / repulsion forces with structured substrates

Research framework

The adhesion that occurs between a micro-object and a micro-manipulation tool like the end-effectors of a micro-gripper is an important issue in micro-manipulation and micro-assembly. Adhesion forces cancellation or reduction in a predictable way is also a great challenge in microrobotics.

Because the adhesion force is linked to the surface structure of both the object and the gripper, the modeling and the experimental validation of this force for structured surfaces is necessary to plan and achieve reliable microrobotics tasks.

Proposed approach

Force interactions between a micrometric sphere and a structured plane substrate were experimentally studied and modeled. The structured substrate is made of layers of polystyrene PS spheres created by spin coating. The characterization of the pull-off force was performed with a rectangular silicon AFM cantilever with a microsphere glued in place of the standard AFM tip. This microsphere is supposed to interact with 3 spheres at the most on the structured substrate because of the chosen spheres radius on the substrate. All experimental measurements were performed with the NANOROL robotics platform specifically dedicated to micro-force measurements. A multisphere van der Waals force model was proposed. This model and the experimental measurements show the existence of an optimal value of the microspheres radius which minimizes the adhesion. The aim is to extend this model and to demonstrate the relationship between this minimum value and the microsphere’s diameter and nature.


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