PhD offer:
Full 3D surface reconstruction with the scanning electron microscope for metrological and educational applications

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1 Context

For a long time, FEMTO-ST has been designing and fabricating microrobotic components: sensors, actuators, kinematics. This activity has taken a new step with the ROBOTEX platform that enables accurate imaging, positioning, folding and attaching [RLR+18]. Even if outstanding results have been obtained, the process can be improved by integrating a dimensional characterization step: measurement of components geometry to see if they fit design. A practical and non-destructive solution may consist in performing full 3D surface reconstruction of components with the scanning electron microscope and achieve either measurement of geometry or comparison of 3D designed and fabricated models.

Micromachining is defined as cutting processes at microscale. It involves a cutting tool whose edge is considered as having a radius, the cutting edge radius, that is determined by carbide grain size, coating thickness and manufacturing process, of the tool. It is a major parameter: it affects the whole machining process and workpiece quality, the weaker the radius, i.e. less than ten micrometers, the better machining quality. It is then important, but challenging, to estimate its value with accuracy. A better solution may consist in 3D reconstructing tool edge and best fit it with a cylinder.

A pollen grain consists of reproductive male cells surrounded by two walls. The inner wall or intine, thin and composed of cellulose, maintains the integrity of the reproductive material. The outer wall or exine, made of sporopollenin, an inert biopolymer, provides the rigid and sculptured framework of pollen and serves to encapsulate and protect the reproductive material.
Sporopollenin-based exine exhibits some outstanding features, resistance to biological attacks (pollination), chemical attacks (solvents, etc.), physical attacks (high temperatures, changes of temperature, UV, etc.) as well as mechanical stresses [dLVvB05][BBB+15]. This has led to the use of pollen grains in palynology-palaeoecology as markers to trace the history of the vegetation cover in relation with changes in climate and impacts of human activities [JBPB+07], [MBG+16]. The mean issue with pollen is its size, that ranges from 7 to 150 μm: how to see, handle and learn pollen grain ? The other issue with pollen is the great complexity of exine which makes it particularly difficult to learn. Currently, most of the time, 2D images obtained from the optical microscope are used, but these images are known to lack of accuracy and more particularly do not say anything about the three-dimensionality of pollens. A solution may consist in performing full 3D reconstruction of pollen grains in a scanning electron microscope and then 3D printed the accurate obtained models at larger scales.

Finally the application contexts of the work are three-dimensional metrology of microrobotic components and micromachining tools, and pollen educational materials.

2 Objective

The main objective of the work consists in developing a solution for full 3D surface model reconstruction of the types of objects described above, from their images obtained with the scanning electron microscope of the ROBOTEX platform, along with an effective auto-calibration method enabling accurate SEM model and motion estimation.
Many issues have to be solved including: automatic acquisition of about 100 images per object (microrobot calibration and control, SEM dynamic autofocusing), accurate autocalibration using regularized cost and global scatter search, dense matching, depth maps merging, filling and filtering of 3D point clouds (computer vision).

The work will be validated on three cases study: 3D metrology of microrobotic components, 3D metrology of micromachining tool, and 3D printing of pollen for palynology educational purpose.

3 Related work

Despite their differences, in electron microscopy as in optical microscopy, geometric 3D reconstruction is the most widespread. This popularity can be explained by its robustness to image noise or surface texture. It includes: detection of salient points, matching of salient points between image pairs, possible calibration, i.e. calculation of imaging models and motion, calculation of fingerprints from matching, calculation of 3D points, possible refinement of 3D points by adjusting beams. Therefore the main limitation of this approach is the existence of salient points: this is the case only for well-textured surfaces [FH+15].

For several years research on 3D reconstruction in the electron microscope has been very active. Many publications have been published recently, they can be classify according to two features:

- the level of full 3D completion, that is relative to the use of multiple stereo-images of object and the range of rotation, from some degrees to 360 degrees,
- the level of auto-calibration, i.e. if calibration is manual (using a calibration rig), automatic or semi-automatic (assume model or motion is known).

In detail, one can consider:

- partial reconstruction (only a single stereo-image) with manual calibration: [PBB+02], [JF07], [YAK17],
- partial reconstruction with auto-calibration: [Cor05], [Kud17], [KGR+20]
- full reconstruction (multiple stereo-image) with semi-automatic calibration: [ER15], [GSY+16], [GLCGR+17].
- full reconstruction with autocalibration: [KDZN10], [TKA+15], [THB+16], [OTF+16].

The work of the current project targets full reconstruction with an effective auto-calibration, i.e. a regularized cost along with a scatter global search.

4 Desired profile

A person with high skills in 3D reconstruction, Optimization, Robotics, OpenCV, PCL, NLOpt, Ceres, C++, Linux.

For application, send a CL and CV to sounkalo.dembele@femto-st.fr

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