Phd Subject: **Uncertain and Incomplete knowledge analysis in 3D surface model estimation**

PhD Subject subtitle: **Representing and propagating uncertain and incomplete knowledge: Application to quality evaluation of a surface model**

Research director: Sebastien Destercke
Laboratory: U.M.R. C.N.R.S. 7253 Heudiasyc, Université de Technologie de Compiegne
Contact email: sebastien.destercke@hds.utc.fr

CNES Team: Sarrazin Emmanuelle, Dubois Emmanuel, DSO/SI/2A CNES service
Contact email : emmanuelle.sarrazin@cnes.fr emmanuel.dubois@cnes.fr

CS Team: *Loic Dumas*
Contact email: loic.dumas@csgroup.eu

Keywords: 3D, DSM, Uncertainty, Satellite

Description:

Working with 3D images is important in many applications, for example in urban planning or to understand climatic impact in mountainous or icy landscapes. In this context, the satellite is an interesting component thanks to its ability to see large spaces in one sweep, at a lower cost than an airplane. CNES supports many activities in 3D, such as the CO3D project with Airbus, which will aim to map the earth in 3D with dedicated satellites.
CNES has a 3D restitution pipeline which generates, from an image pair, the corresponding Digital Elevation Model (DEM). This 3D tool called CARS is publicly available [6].

This pipeline is composed of the following 3D steps:

- Epipolar geometry transformation (image alignment)
- Dense matching between images to identify homologous points: Pandora tool [7]
- Triangulation of homologous points thanks to the image geometric models
- Rasterization from a point cloud to a 2.5D image

In each of these stages, uncertainty can appear:

- on the input data (geometric models, noise on the image detectors, etc.)
- on the method for computing epipolar images
- on dense matching method
- on rasterization method

Uncertainty can be linked either to stochastic uncertainty (measurement noise) or to epistemic uncertainty resulting from a lack of knowledge, especially in the models. Currently, uncertainty is propagated in the 3D pipeline without being precisely quantified or modeled. While probability distributions are sufficient to model purely stochastic or random uncertainty, many works suggest that it is not sufficient to describe uncertainty due to lack of knowledge or imprecision. This modeling can be done, for example, by using sets of probabilities or fuzzy sets. This thesis aims at analyzing the different types of uncertainty and to see how to represent them using a wide set of mathematical tools like belief functions, distributions of possibilities, etc. The objective is to apply mathematical tools for modelling and propagate imprecise and uncertain knowledge through the aforementioned pipeline, and to check how classical approaches currently used can be improved to better take into account and better quantify uncertainty in the final 3D result.

The objectives are to:

- Understand the steps of a 3D pipeline and the associated uncertainties through the CARS tool.
- Identify mathematical methods for representing and propagating uncertainties in the 3D pipeline
    - Define how to represent information of a random or imprecise nature in the pipeline
    - Understand how uncertainty propagate within the pipeline
- Quantify the impact of uncertainty in the different stages in order to be able to identify which parameters impact the most on the final uncertainty.
- Select which uncertainties to primarily reduce according to their characteristics and importance in order to improve the confidence in 3D restitution
- Propose solutions for evaluating and improving the quality of a digital surface model, such as:
    - Generating an uncertainty interval for the elevation measurement and a way to represent uncertainty in the end results to users.
    - Providing avenues for understanding uncertainty in the 3D pipeline

If all of these problems are already well treated in classical probabilistic approaches, some of them still need to be explored with more generalized theories, i.e., issues such as sensitivity analysis allowing to identify the main sources contributing to the end uncertainty, or the establishment of experimental and sampling plans to reduce uncertainty.

Context:

The PhD student will be part of a new cooperation between Heudiasyc (specialized in severe uncertainty management) on one hand, localized in Compiègne (near Paris), and CS and the CNES (specialized in 3D image treatment) on the other hand, localized in Toulouse. The student will be expected to spend significant time at each institution, in order to gain the required expertise and knowledge. As such, the student will benefit from a strong multi-disciplinary expertise, and will develop connections with both the academic and private sector.

Sought profile:

Applicants should demonstrate through their formation, previous professional experience and records a strong background in mathematics and computer science. Ideally, this will come with a strong expertise and interest in image processing and/or in uncertainty modelling and processing. The applicant should provide the following elements when applying:

- A complete CV
- A motivation letter showing the student interest for the topic

We will retain the right to ignore the application if the applicant fails to provide these elements, or provide a generic, top-off-the-shelve recommendation letter. To avoid this latter issue, the applicant is invited to at least consult reference [5], and possibly [1]. In addition, the applicant is encouraged to provide additional information such as

- Reference letters or contact to referees
- Evidence of the quality of their background (previous grades, achievements such as publication, published software, etc.)

References:

[1] Beer, Michael, Scott Ferson, and Vladik Kreinovich. "Imprecise probabilities in engineering analyses." *Mechanical systems and signal processing* 37.1-2 (2013): 4-29

[2] Cédric Baudrit. Représentation et propagation de connaissances imprécises et incertaines : Application à l'évaluation des risques liés aux sites et sols pollués.. Mathématiques [math]. Université Paul Sabatier - Toulouse III, 2005. Français. https://tel.archives-ouvertes.fr/tel-00011933

[3] Höllmann, M., Mehltretter, M., and Heipke, C.: GEOMETRY-BASED REGULARISATION FOR DENSE IMAGE MATCHING VIA UNCERTAINTY-DRIVEN DEPTH PROPAGATION, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-2-2020, 151–159, https://doi.org/10.5194/isprs-annals-V-2-2020-151-2020, 2020.

[4] Mehltretter, M.: UNCERTAINTY ESTIMATION FOR END-TO-END LEARNED DENSE STEREO MATCHING VIA PROBABILISTIC DEEP LEARNING, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-2-2020, 161–169, https://doi.org/10.5194/isprs-annals-V-2-2020-161-2020, 2020.

[5] Michel, J., Sarrazin, E., Youssefi, D., Cournet, M., Buffe, F., Delvit, J. M., Emilien, A., Bosman, J., Melet, O., and L'Helguen, C.: A NEW SATELLITE IMAGERY STEREO PIPELINE DESIGNED FOR SCALABILITY, ROBUSTNESS AND PERFORMANCE, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., V-2-2020, 171–178, https://doi.org/10.5194/isprs-annals-V-2-2020-171-2020, 2020

[6] https://github.com/CNES/cars

[7] https://github.com/CNES/Pandora