**Title:** Design guidelines for acoustic and microwave trees Imaging based on statistical analysis

**Supervisors:**

- Antoine ROUEFF (Ecole Centrale Marseille, Insitut Fresnel, antoine.roueff@fresnel.fr)
- Philippe LASAYGUES (CNRS, Laboratoire de Mécanique et d'Acoustique philippe.lasaygues@lma.cnrs-mrs.fr)
- Amélie Litman (Aix-Marseille Universté, Institut Fresnel, amelie.litman@fresnel.fr)

**Scientific field**:

Acoustic and microwave imaging, applied statistics for performance analysis

**Subject:**

When a characterization instrument is being conceived, one of the key questions is to come up with a design which will provide quantitative results with a given precision. Naturally, one always searches for the best precision, while keeping the instrument as simple as possible. For the device design, it is thus extremely important to predict beforehand the precision of a given device before effectively constructing it. The motivation of this project comes from the finding that most of the present studies in the field of tomographic imaging are mainly concerned with the improvement of imaging algorithms and very few are related to the improvement of the configuration of the measurement device. Our recent literature survey has shown (Diong, Inv. Problems 2015) that since the gain in precision is limited by the amount of information in the measured data, thus one should also inquire for the measurement setup that maximize the amount of information in the data.

In the framework of estimation theory, the system performance can be analyzed based on the measurement model and the available a priori knowledge. Moreover, this analysis can be done based on the amount of information, which can be measured with the Fisher information matrix and prior to the development of advanced data processing/imaging algorithms. The only requirement is to have a good knowledge on the physical mechanisms that occur during the considered experiment and also on the noise model, which can require some experimental expertise.

The purpose of this PhD work is to lead such performance analysis with two types of imaging instruments to improve their design. This work is a direct continuation of a recent PhD thesis (PhD Diong 2012-2015) where the technical and theoretical aspects have been validated on simple examples and several scientific locks have been identified.
As the former PhD work has focused on the development of a methodology but for simple objects (i.e. that can be described with few parameters), the present proposal is meant to be oriented towards more complex objects. This will require developing suitable methods which could either fully incorporate the complexity of the internal structures of the objects to be imaged in spite of the limited information content available in the dataset, or cope with inaccurate models and thus dealing with model error propagation.

The specific context of this PhD work is in direct adequacy with the research focus of the two laboratories: Institut Fresnel and Laboratoire de Mécanique et d'Acoustique. It concerns the nondestructive imaging of standing trees, as wood is a material whose properties depend on its different anatomical features correlated with age and environmental growing conditions. An insight look will thus help the scientists to assess the sanitary state of the forest as well as making decisions regarding the possibility of saving trees. It will also help them in the trees watering, preventing and treating process.

Two types of devices are being considered. The first one, based on ultrasonic waves, will focus on the trunk of the tree. For the time being, it consists of a mechanical array of transducers which may move all around the tree (PhD Arciniegas 2011-2014). The second one, based on

electromagnetic waves, will focus on the roots of the tree. For the time being, it also consists of a mechanical array of antennas which may move above the soil surface (PhD Nounouh 2010-2013). Thanks to these tomographic imaging tools, it is possible to provide a non-destructive characterization of the internal structures of the tree, with varying spatial resolution. The two types of wave are being combined as their penetration depth changes according to the probed region physical parameters.

Based on the statistical performance analysis, the aim is to come up with some design guidelines related to the antennas/transducers positions, their frequency band, and their polarizations (for the electromagnetic case). This theoretical analysis will have direct applications in the construction of the ground penetrating radar and the ultrasonic computed tomography devices. This work will be performed in close relationship with the experimentalists in charge of developing/managing such devices. This will allow to verify the measurement model and to illustrate the potential benefit of the device optimization.

The candidate should have a special interest in estimation theory and statistical signal processing and a strong background in physics, in particular, wave propagation in acoustics or electromagnetism. He will benefit from the knowledge of both laboratories Institut Fresnel and Laboratoire de Mécanique et d'acoustique and will actively participate in the life of both laboratories.

**References:**

Diong M.L., Roueff A., Lasaygues P., Litman A.
"Precision analysis based on Cramer-Rao bound for 2D acoustics and electromagnetic inverse scattering", Inverse Problems (2015) 31(7):075003

A. Arciniegas, L. Brancheriau, P. Gallet, and P. Lasaygues, "Travel-Time Ultrasonic Computed Tomography Applied to Quantitative 2-D Imaging of Standing Trees: A Comparative Numerical Modeling Study," *Acta Acust. United Acust.*, vol. 100, no. 6, pp. 1013–1023, Nov. 2014.

L. M. Diong "Analyse de performances des systemes d'imagerie par diffraction acoustique et électromagnétique à l'aide de la borne de Cramer Rao", doctorat d'Aix-Marseille université, soutenu le 9 décembre 2015.

Thèse Arciniegas A.: http://www.theses.fr/2014AIXM4746

Thèse Nounouh S.: http://www.theses.fr/2013AIXM4750

A. Litman, L. Crocco "Testing inversion algorithms against experimental data: 3D targets" Inverse Problems (2009) 25:020201

S. Nordebo, M. Gustafsson, B. Nilsson, "Fisher information analysis for two- dimensional microwave tomography", Inverse Problems (2007) 23:859

W.C. Chew, "Waves and Fields in Inhomogeneous Media", Van Nostrand Reinhold (1990)