Advanced imaging

Within this research activity, the development and optimization of non-conventionnal techniques for **polarimetric imaging** (spectro-polarimetric imaging, microwave-photonics imaging …) and **ballistic photon imaging through diffusive media** provide tools to better understand light-matter interaction. These research activities are also studied in terms of biomedical applications in collaboration with biologists, in particular for **unconventional biological microscopy**. This research field falls within the dynamics of the “Images & Réseaux “ (Images & Networks) international competitiveness cluster.

Non conventional polarimetric imaging techniques

Polarimetric imaging at the speckle grain scale

Real-time ballistic photons imaging

This research activity, conducted in collaboration with the Raman Research Institute of Bangalore (India), aims at developing imaging systems and dedicated image processing that can provide a visual assistance for navigation (airborne/terrestrial/sea) in conditions of degraded atmospheric visibility. The approaches studied involve light polarization of intensity modulation over long atmospheric trajectories in real conditions and aim at real-time operation. Thanks to the support of the TDF company, we were able to design an experimental setup for polarimetric imaging through fog over kilometric distances (1.3 km) (Fig. 1.a and 1.b). This automated experimental facility has permitted to gather experimental data in real atmospheric conditions (clear sky, haze, light or dense fog, rain, snow, during day or night) [Fad14a].

In parallel, theoretical studies based on information theory tools make it possible to determine the optimal representations of polarimetric signals which maximize visibility contrast of the source [Fad14b]. The available experimental data are used to compare and validate these predictions on real fog conditions over kilometric distance. It has thus been confirmed recently that the benefit of polarimetric imaging with respect to a standard intensity detector is considerably increased and can outperform standard intensity images by an order of magnitude in terms of contrast enhancement when statistical fluctuations in the two acquired polarimetric images are significantly correlated. We have also shown that taking into account this correlation enables an optimal and easily implemented representation to be identified, and which efficiently increases visibility contrast of the polarized beacon in all atmospheric conditions studied [Swa15]. Such adaptive representation ensures the best compromise in terms of contrast enhancement whatever be the visibility conditions, by computing the best linear combination of the two polarimetric channels acquired, so as to provide the end-user with an exploitable final image.

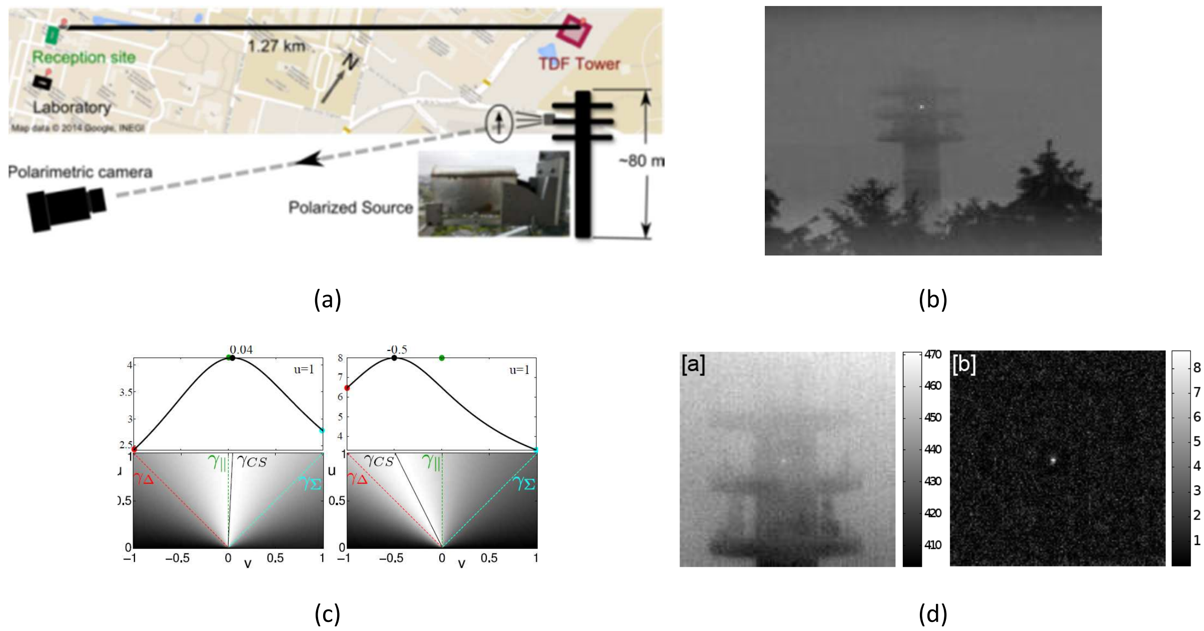

Fig. 5: (a) Schematic view of the polarimetric imaging experiment through fog over long distances. (b) A polarized beacon settled on a telecommunication tower (TDF) is imaged with a polarization-sensitive camera developed for this experiment and which acquires two images along two linear orthogonal polarization directions. (c) Taking into account the partial correlation of intensity fluctuations in the two acquired polarimetric images allows to evidence an optimal signal representation, which differs from usual standard polarimetric representations, and which maximizes the visibility contrast of a polarized beacon in fog (d-[b]) with respect to a standard intensity image (d-[a]).

Still in collaboration with the Raman Research Institute, another ballistic photon imaging technique is being investigated in the FOTON-DOP team. It consists of modulating the intensity of a non-polarized light beacon at high frequency (typically 10 MHz for a kilometric working distance), and proposing an imaging technique capable of « filtering » the ballistic photons modulated at high frequency. In that context, we have analyzed the performance and the software acceleration of digital quadrature lock-in detection at low frequency [Sud16] on the one hand. On the other hand, relying on simple atmospheric scattering model (diffusion approximation) and on information theoretic tools, we have computed the optimality bounds for the estimation of the scattering parameters of the fog (absorption coefficient, scattering coefficient), and of the visibility contrast of an intensity-modulated beacon [Pan16]. This work provides quantitative conclusions about the optimal operating frequencies and the limit working distance of the technique.

In parallel with these theoretical approaches, we have recently patented an original optical device capable of demodulating optical signals in an image in real-time and in quadrature (i.e., without reference or synchronization). This approach, which has been experimentally validated so far at low frequency (10-100 kHz), is characterized by its simplicity in terms of electronical components, and by its versatility. It could in principle offer a solution to carry out an « imaging lock-in detection » of signals up to 10 GHz.

Selected publications:

[Fad14a] J. Fade, S. Panigrahi, A. Carré, L. Frein, C. Hamel, F. Bretenaker, H. Ramachandran and M. Alouini, "Long range polarimetric imaging through fog," Applied Optics 53 (18), 3854-3865 (2014).

[Fad14b] J. Fade, S. Panigrahi and M. Alouini, "Optimal estimation in polarimetric imaging in the presence of correlated noise fluctuations," Optics Express 22, 4920-4931 (2014).

[Pan15] S. Panigrahi, J. Fade and M. Alouini, "Optimal contrast enhancement in long distance snapshot polarimetric imaging through fog," submitted to Journal of Optics, (2015).

[Sud16] S. Sudarsanam, J. Mathew, S. Panigrahi, J. Fade, M. Alouini and H. Ramachandran, "Real-time imaging through strongly scattering media: seeing through turbid media, instantly," Scientific Reports, 6, 25033 (2016).

[Pan16] S. Panigrahi, J. Fade, H. Ramachandran and M. Alouini, "Theoretical optimal modulation frequencies for scattering parameter estimation and ballistic photon filtering in diffusing media," Optics Express 24, 16066-16083 (2016).

Biophotonic imaging

PhD theses (*past* / ongoing):

Swapnesh Panigrahi, « Real-time imaging through fog over long distances », 2016

François Parnet, *« Imagerie spectro-polarimétrique temps réel à longue distance par approche optique-hyper-fréquence et traitement avancé d'images spectro-polarimétriques »*

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Thales Research and Technology (Palaiseau)

Institut Fresnel (Marseille)

IRFU, Service d'Astrophysique, CEA (Gif-sur-Yvette)

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