PROPOSITION DE SUJET DE THÈSE

Intitulé : Wavefront shaping for free-space optical communications through fog

Référence : **PHY-DOTA-2023-14**
(à rappeler dans toute correspondance)

Début de la thèse : octobre 2023	**Date limite de candidature :** 01/05/2023

Mots clés :

Adaptive Optics, Wavefront Shaping, Scattering Media, Fog, Free-Space Optical Communications, Cryptography

Profil et compétences recherchées :

Engineering school of Physics, Optics, Master 2 in Physics

Présentation du projet doctoral, contexte et objectif :

Context:
Free-space optical communication (FSO) represents an attractive solution to address the problems of radio frequency saturation and the growing need for high-speed data exchange. This technic is very promising for terrestrial links, campus network, private communication and even ground satellite links [1]. Recently a team has demonstrated that secure transmission can be achieved by synchronizing two quantum cascade lasers (QCL) operating in a chaotic regime in the mid-infrared spectral domain [2]. In this regime, the signal emitted by the laser is composed of time-irregular, unpredictable pulses that formed an encrypted message. These major results which have been awarded [3] open the path towards secure communications with powerful but eye-safe compact sources. However, in presence of atmospheric disturbances such as fog, the optical signal undergoes temporal and spatial distortions that increase with the number of scattering events. So when the distance or the density of water droplets gets high, the communication signal becomes unreadable [4].
Last decade great progresses have been made for focusing light and imaging through highly scattering media using spatial light modulators [5][6][7][8]. Their large number of actuators is required to control the great number of optical modes generated by multiple scattering and improve significantly the performance of the system. The approaches of imaging or focusing through complex media that have emerged in the literature are generally applied to static or weakly turbid media. For such media, the strategy consists in computing a transmission matrix which establishes a relationship between the input and the output complex field. But due to the large number of actuators to address, this calibration procedure is slow and becomes redhibitory for dynamic media such as thick fogs.
After passing through a scattering medium, the field of a coherent optical beam is composed of speckles whose light intensity is spatially randomly distributed. Preliminary works on fog carried out by ONERA and the LKB show that the decorrelation time of the speckles, a key parameter, can be compatible with the bandwidth of the new generation of fast actuator modulators available on the market. This means that it should be possible to implement a phase conjugation (time reversal) method for FSO through fog, a relevant technique to determine the optimal correcting wave, and avoid long calibration process of the channel [9].
It is extremely complex to model the impact of a very turbid media on an electromagnetic field. It is therefore necessary to combine modeling and experimental approach to estimate the performance of phase conjugation.

Research project:
The challenge of the thesis is to develop innovative approaches for optical communication in turbid media and to estimate the gain brought by the adaptive correction (wavefront shaping) in terms of distance, signal to noise ratio and bandwidth. These works will be supported by theoretical modeling and experimental measurements. under low turbidity conditions performed with a laboratory fog greenhouse.
The degradation of various families of chaotic signals after propagation through fog will be estimated. Based on recent theoretical modeling, new strategies to preserve the signal immunity will be explored. The capacity of an adaptive optics system to enhance the FSO performance will then be evaluated from the spatial and temporal impacts of the scattering medium, the performance of the components (bandwidth, number of actuators,...) and for wavelengths spanning from the near to the long infrared domain. A complete telecommunication architecture including wavefront shaping ability should be proposed at the end of this research project.

Environment:
This PhD will carry out in close collaboration with Sylvain Gigan (Laboratoire Kastler Brossel) and the Institut of Fresnel. The PhD will be conducted at ONERA and TelecomParis Tech and will thus benefit from interactions with talented researchers in telecommunication and adaptive optics.
We are looking for an applicant with skills in experimental work, as well as a taste for theoretical study.

[1] C. Sauvage, C. Robert, B. Sorrente, F. Grillot, et D. Erasme, « Study of short and mid-wavelength infrared telecom links performance for different climatic conditions », SPIE Remote Sensing,Strasbourg, Septembre 2019.

[2] O. Spitz, A. Herdt, J. Wu, G. Maisons, M. Carras, C.-W. Wong, W. Elsäßer & F. Grillot,, « Private communication with quantum cascade laser photonic chaos », Nature Communications, https://doi.org/10.1038/s41467-021-23527-9.

[3] O. Spitz, “Mid-infrared quantum cascade lasers for chaos secure communications”, sous la direction de Frédéric Grillot et Mathieu Carras, Université Paris-Saclay, décembre 2019, Prix de these DGA 2021.

[4] C. Sauvage, « Impact de l’environnement atmosphérique sur les liaisons optiques sans fil pour la ville du futur », Thèse, 2020.

[5] M. Vellekoop and A. P. Mosk, « Focusing coherent light through opaque strongly scattering media », Optics Letters, Vol. 32, No. 16, 2007.

[6] A. P. Mosk *et al.,* « Controlling waves in space and time for imaging and focusing in complex media, *Nature Photonics,* Vol 6, 283-292, 2012.

[7] M. Mounaix, H. Defienne, S. Gigan, « Contrôle spatio-temporel de la lumière en milieux complexes », Photoniques, N° 92, 2018, https://doi.org/10.1051/photon/20189229.

[8] S. Gigan et al., “Roadmap on wavefront shaping and deep imaging in complex media”, Journal of Physics: Photonics, vol. 4.

[9] B. Blochet, L. Bourdieu, and S. Gigan, «Focusing light through dynamical samples using fast continuous wavefront optimization », Optics Letters, Vol. 42, Issue 23, 2017.

Collaborations envisagées:

Laboratoire Kastler Brossel, Institut Fresnel

Laboratoire d’accueil à l’ONERA:	**Directeur de thèse:**
Département : DOTA/HRA	Nom : Frédéric GRILLOT
Lieu (centre ONERA) : Châtillon	Laboratoire : Telecom Paris Tech
Contact : Béatrice SORRENTE	Tél. : 01 75 31 93 00
Tél. : 01 46 73 48 53 Email : beatrice.sorrente@onera.fr	Email : frederic.grillot@telecom-paris.fr

Pour plus d’informations : https://www.onera.fr/rejoindre-onera/la-formation-par-la-recherche