MASTER 2 AND DOCOTORAL THESIS PROPOSAL

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Thesis possibility after internship: YES

MID-INFRARED FULL-FIELD OCT FOR DEEP IMAGING IN OPAQUE MEDIA

To probe optically the subsurface of a scattering medium using an external illumination of intensity I_0, the effect of multiple scattering is such that the quantity of ballistic photons, i.e. photons that pass through the medium without undergoing multiple scattering events, decreases exponentially with the distance traveled by light in the medium. Indeed, for a layer of thickness L of a medium showing both absorption and scattering, the intensity of ballistic photons is $I_b = I_0 \exp(-L / l_s).\exp(-L / l_a)$, $l_{s,a}$ being the scattering and the absorption mean free path, respectively. An object located within a few scattering mean free paths below the surface produces a blurred image on a camera; deeper objects become invisible as the few remaining ballistic photons are overwhelmed by multiply scattered ones reaching the detector.

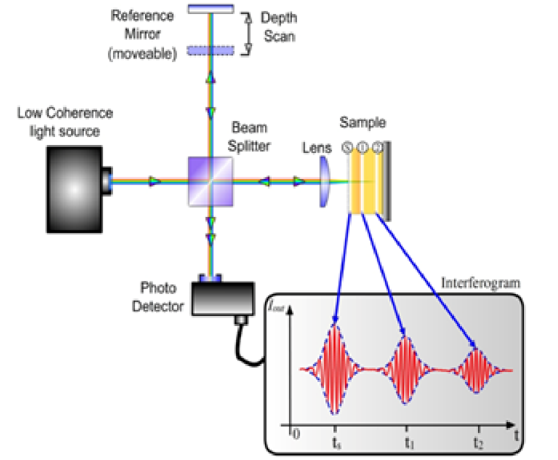

Figure 1: Schematic graph of an early time-domain optical coherence tomography (TD-OCT)

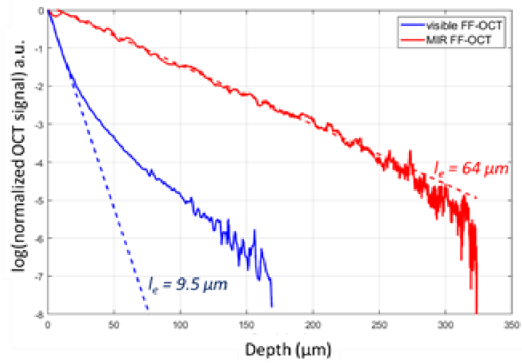

Figure 2: FF-OCT measurement of the extinction mean-free-path l_e of white acrylic paint in the MIR spectral range (MWIR, 3-5 µm) compared to the same measurement at visible wavelengths.

High-resolution, depth-resolved imaging beneath scattering media is nevertheless possible using **Optical Coherence Tomography (OCT)**, based on low-coherence interferometry [Huang1991]. Broadband sources allow optical "slicing" into 3D samples: interference occurs only at depths where the optical path difference between reference and sample beams is zero (Figure 1). This selectively detects singly backscattered (ballistic) photons while rejecting the diffuse background, yielding clear tomographic images.

Conventional OCT acquires such slices point by point, requiring mechanical scanning. At the **Institut Langevin**, Claude Boccara's group pioneered an alternative **Full-Field OCT (FF-OCT)** approach, where a camera simultaneously detects multiple pixels under wide-field illumination [Dubois2002] [Vabre2002]. Each depth scan yields an *en-face* image with superior lateral resolution, and the use of spatially incoherent light makes the technique far less sensitive to optical aberrations [Barolle2021]. Since OCT imaging relies on ballistic photons, its penetration depth is limited by the **extinction mean free path** l_e, defined as $1/l_e = 1/l_s + 1/l_a$. Consequently, the technique has been mainly applied to **biological tissues**, where $l_s \approx 100\ \mu m$ or more in the **visible–near-infrared range** (the so-called biological transparency window). In contrast, OCT becomes ineffective for subsurface imaging of **opaque, highly scattering materials**, where l_s is only a few μm in the same spectral range.

By integrating a mid-wave or long-wave infrared (MWIR/LWIR) camera, similar to those used in thermal imaging, into an interferometric setup combined with a broadband infrared source, we aim to achieve deep imaging through diffusive and/or opaque layers such as paints, coatings, plastics, ceramics, or aged varnishes.

Full-Field OCT (FF-OCT) remains largely unexplored in the mid-IR range. This project will therefore address both fundamental questions on infrared light propagation in complex scattering media and applied challenges in several fields. This internship offers an opportunity to contribute to the development of a new generation of infrared interferometric imaging tools, expanding the reach of OCT beyond its traditional spectral limits. Anticipated applications include:

- Cultural heritage analysis, enabling visualization beneath painted surfaces and ceramic glazes.

- Non-destructive testing, particularly for detecting subsurface defects in industrial coatings used in aerospace and advanced manufacturing.

Importantly, we have already validated the proposed concept by constructing a **basic interferometric mid-IR prototype** combined with a **MWIR camera**. As shown in Figure 2, using acrylic paint as a scattering test sample, the **mean OCT signal intensity** decays exponentially with depth below the surface. From this decay, we determine an extinction mean free path $l_e = 64\ \mu\mathrm{m}$. For comparison, the same measurement performed at visible wavelengths yields $l_e = 9.5\ \mu\mathrm{m}$, clearly demonstrating the **advantage of mid-infrared FF-OCT** for **deep subsurface imaging**.

[Huang91] D. Huang, et al.Optical Coherence Tomography, Science 254, 1178 (1991).
[Dubois2002] A. Dubois, L. Vabre, A.C. Boccara, et E. Beaurepaire. High-resolution full-field optical coherence tomography with a Linnik microscope. Applied Optics 41, 805 (2002).
[Vabre2002] L. Vabre, A. Dubois, and A. C. Boccara. Thermal-light full-field optical coherence tomography. Optics Letters 27, 530 (2002).
[Barolle2021] V. Barolle et al. Manifestation of aberrations in full-field optical coherence tomography. Optics Express 29, 22044 (2021).