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SOLUS Project: Bringing Innovation into Breast Cancer Diagnosis and in the Time-Domain Diffuse Optical Field

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Abstract: To improve the specificity of breast cancer diagnosis SOLUS combines ultrasound, shear-wave elastography and time-domain diffuse optical tomography in a multimodal imaging system. An innovative compact device for time-domain multi-wavelength diffuse optics was also developed. © 2020 The Author(s)

1. Rationale of the SOLUS project

In women, breast cancer is the most common cancer type. Early diagnosis plays a fundamental role to improve the patients' quality life and increase their chances of survival. To make the early diagnosis more reliable and sustainable for the health care systems, diagnostics tools characterized by cost-effectiveness, non-invasiveness, high specificity and sensitivity are required. The SOLUS project [1] works to help meet this clinical need. Indeed, it aims to develop a new multimodal tomographic breast system, which embeds three different non-invasive imaging techniques: ultrasound imaging (US), shear-wave elastography (SWE) and time domain diffuse optical tomography (TD-DOT). Each of them provides specific information, thus offering potential to improve the specificity of diagnosis. More in detail, US will assess the presence of a lesion and provide the *a-priori* information on the lesion's morphology to guide TD-DOT; SWE will evaluate tissue stiffness, while TD-DOS will provide information about tissue composition (*i.e.* blood, lipid, collagen and water concentrations [2]) through the estimation of the optical properties (*i.e.* absorption - μ_a - and reduced scattering - μ_s' -).

To realize a single medical system embedding the above described techniques, a commercial instrument for US and SWE (Aixplorer Mach 30 by SuperSonic Imagine S.A.) has been equipped with eight innovative photonics modules devised on purpose for this project and arranged around the ultrasound transducer (see Figure 1),

The SOLUS project, indeed, has 2 main potentially disruptive outcomes: i) the fabrication of an innovative and cost-effective instrument to improve the specificity of the breast cancer diagnosis, thus reducing the number of needless biopsies and consequently patient's discomfort and economic burden for healthcare systems; ii) the realization of a small, stand-alone, low-cost and multispectral system for TD-spectroscopy, which may open the use of diffuse optics in many fields (from medical imaging, to athlete training monitoring to non-destructive assessment of fruit quality).

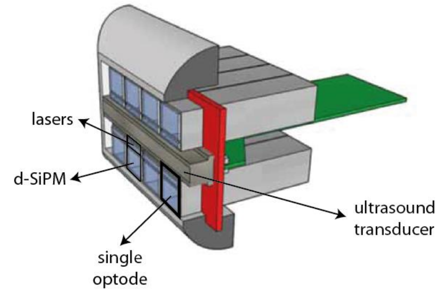

Fig. 1. Mock-up of the SOLUS. Around the US transducer, 8 optodes have been arranged.

2. Technological innovation introduced by the SOLUS project: the optode

The optode, *i.e.* the basic photonic module of the SOLUS system, features a state-of-the-art time domain diffuse optical spectroscopy system, and it represents a stand-alone device for a wide range of potential applications. Indeed, it embeds 8 pulsed laser diodes with a wavelength range between 635 and 1064 nm (suitable wavelengths were chosen to sample the different constituents of breast tissue), a large-area fast-gated digital Silicon Photomultiplier (dSiPM) and the acquisition electronics to record the distribution of time-of-flight (DTOF) of re-emitted photons. The fast-gating capability of the detector enables to increase the dynamic range of the measurements and to perform measurements even at short source-detector separations. Indeed, the use of the fast-gating technique is based on the slicing of the DTOF curve and in the acquisition of each portions of the DTOF at a given count-rate, thus significantly improving the number of acquired late photons and the dynamic range of the measurements [3].

Figure 2 reports an example high dynamic range DTOFs (acquired on a homogeneous phantom with $\mu_a = 0.2$ cm^{-1} and $\mu_s' = 10$ cm^{-1} at 800 nm) recorded with the optode and reconstructed following the procedure described in Ref. [3]. From the level of noise before the peak, it is evident that the increase in the dynamic range is between one and two decades, depending on the wavelength.

The optode was also characterized following shared protocols for diffuse optics instruments, to assess its basic performances (*e.g.* light harvesting, instrument response function – IRF – shape and temporal stability, etc.), as well as its capability of detecting an optical perturbation buried in depth and of recovering its optical properties. It was demonstrated (data not shown) that, due to the large area, the light harvesting is at least one order of magnitude larger than for state-of-the-art systems, while the performances in terms of IRF shape and stability, detection of deep inhomogeneities and recovery of the absorption properties is in line with state-of-the-art systems. The recovery of the scattering coefficient is instead more critical.

In conclusion, we present the SOLUS project, explaining the innovation it will bring into the diagnosis of the breast cancer as well as in the time domain diffuse optics field. Indeed, the production of a compact, cost-effective and multi-wavelength diffuse optical spectroscopy system based on large area fast-gated detector is opening new perspectives in the application of diffuse optics in several fields.

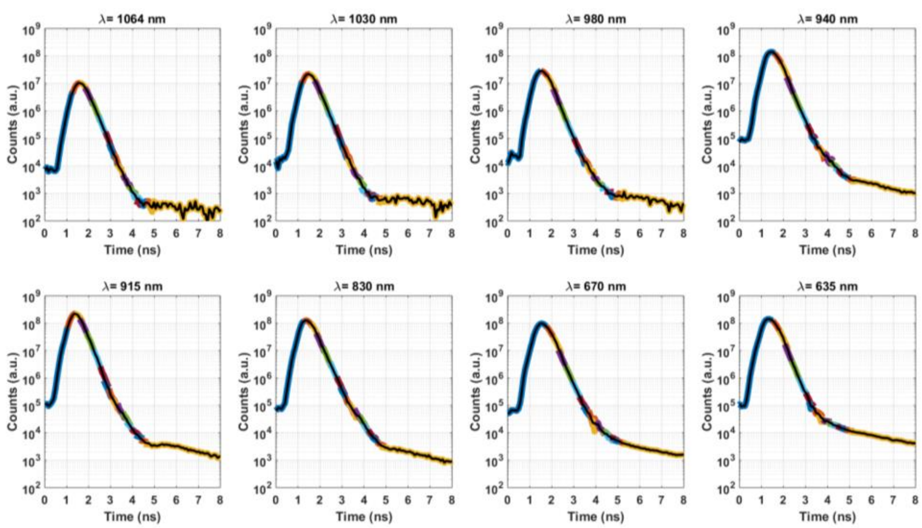

Fig. 2. Reconstructed DTOFs. The colors represent the distinct portions of the gated curves used for reconstruction (for details on reconstruction procedure see Ref. [3])

Acknowledgment

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3. References

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