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An innovative 8 channels system for time-resolved diffuse optical tomography based on SiPMs

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***Abstract*—We present the design of a novel 8 channels system for time resolved optical tomography based on Silicon Photomultipliers (SiPMs), therefore knocking down cost and complexity of this technique and paving the way to a widespread diffusion. We validated the system performances on phantoms.**

Keywords—Time Resolved Diffuse Optical Tomography; Silicon Photomultipliers; Time-Correlated Single-Photon Counting;

INTRODUCTION

Diffuse Optical Tomography (DOT) [1],[2] allows to obtain 3D maps of optical proprieties of biological tissues by injecting light into the sample and recollecting the re-emitted photons in completely non-invasive way. The use of the Time-Resolved (TR) technique [3] allows to encode the depth reached by photons in their arrival time. Indeed, photons probing deep structures will travel longer, thus being remitted later in time with respect to those probing only the superficial layer.

State-of-the-art instruments for TR-DOT (e.g. MONSTIR II [4]) are essentially created by the means of photocathode-based detectors, such as photomultiplier tubes (PMTs). The use of PMTs is related to the need of having wide active area and single photon sensitivity to collect the faint light signal coming from the diffusive sample. However, these detectors are extremely bulky and fragile and can be damaged if exposed to high light intensity, therefore resulting with whole system complexity that hampers the widespread diffusion of TR-DOT. Furthermore, state-of-the-art systems makes use of a PC-hosted Time-Correlated Single-Photon Counting (TCSCP) board for each detection channel, thus sensibly increasing the overall costs.

Only recently Silicon Photomultipliers (SiPMs) [5] have been proposed as a possible revolutionary alternative to PMTs [6],[7] even developing instruments for clinical studies [8]; exploiting these recent results, we built a proof-of-principle of compact 8-channels detection system for TR-DOT based on SiPMs and on an 8-channels Time-to-Digital Converter (TDC). The combination of time-resolved SiPMs and multichannel TDC offers the advantage of being robust, compact and inexpensive, thus potentially knocking down costs and complexity of TR-DOT. To validate the instrument performances, we executed a tomographic reconstruction of an homogenous phantom in which an absorbing inclusion was buried in depth.

EXPERIMENTS AND RESULTS

As a light source, we used a 689 nm wavelength pulsed diode laser (PDL 800, Picoquant GmbH, Germany) at a repetition frequency of 40 MHz, featuring an average output power of about 1 mW. The re-emitted photons were collected by 8 channels, each one based on a commercially available SiPM (1.7 mm^2 area, S13360-1350CS, Hamamatsu Photonics, Japan) with custom-made, miniaturized ancillary electronics. Indeed, for each channel a small (30 mm x 6 mm) front-end Printed Circuit Board (PCB) was designed to optimize the timing performance of the detectors (i.e. Single-Photon

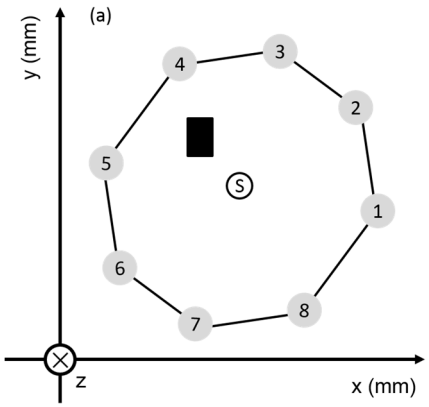

Figure 1. Disposition of source (S), the 8 SiPM channels (identified by a number) and inclusion (black rectangle).

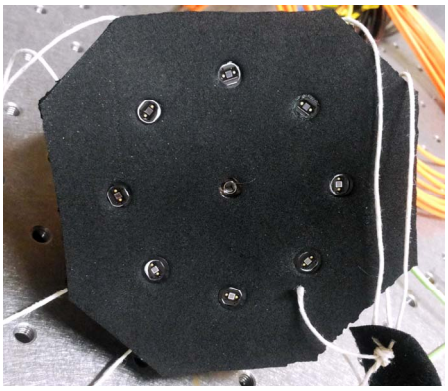

Figure 2. Picture of the designed probe. The laser source, in the center, is surrounded by the 8 SiPM channels

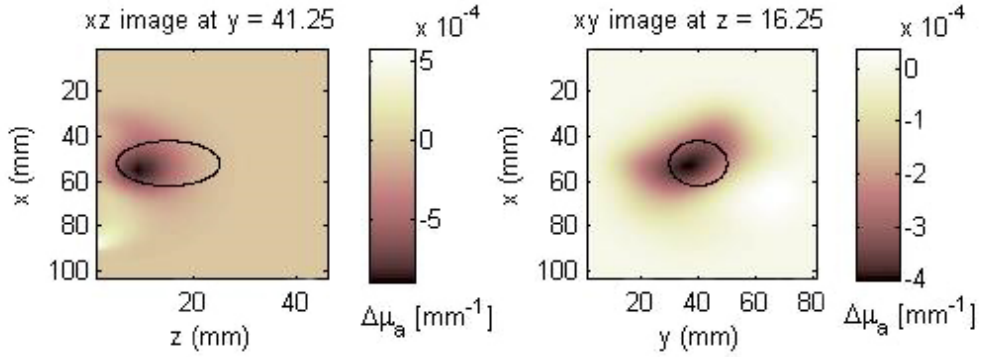

Figure 3. Tomographic reconstructions of the inclusion on the xz plane (y= 42.5 mm) and xy one (z= 17.5 mm).

Timing Resolution (SPTR) lower than 80 ps [9]). This PCB embeds the circuits to bias the detector and to amplify the faint single-photon avalanche signal (~1 mV) up to a well-detectable level (~50 mV). Each SiPM channel can be placed directly in contact with the diffusive sample under investigation, thus avoiding the use of optical fibers and considerably increasing the light harvesting thanks to the wide detector area (1.7 mm^2) and numerical aperture (~1).

To reconstruct the Distribution of Time of Flights (DTOF) of photons, each SiPM output is connected to one input channel of the TDC (SC-TDC-1000/08S Surface Concept GmbH, Germany). Every signal is temporally correlated to the absorption of one photon within the detector active area. In this way, the 8 channels simultaneously reconstructs the DTOF curve emitted by the sample where the detector is placed. To test our system we made use of an homogeneous phantom [10] (μ_a= 0.1 cm^{-1}; μ'_s= 10 cm^{-1}) embedding a totally absorbing inclusion (whose effect is equivalent to a $\Delta\mu_a$ = 0.04 mm^{-1} over a volume of 1 cm^3) at a depth of 15 mm. In Fig.1 is schematized how the detectors were disposed on a circular geometry with the injection fiber in the center and the source-detectors distance was set at 30 mm. The inclusion was posed off-axis at the position x = 52 mm, y = 41.25 mm and z = 16.25 mm. A picture of the probe with the described geometry is reported in Fig.2. The tomographic reconstruction was done considering a semi-infinite medium and using the perturbative approach under the Born approximation [1]. Fig. 3 shows, in terms of μ_a variation, the reconstructed position of the inclusion in both the xy plane (on the right at z = 16.5 mm depth) and the xz one (on the left at y = 41.25 mm) . It is worth noting how the inhomogeneity is well detected and positioned within the volume.

CONCLUSIONS

We developed and characterized a new compact and low-cost 8-channels prototype for TR-DOT based on SiPMs and TDC. We tested the sensitivity of the proposed system with phantom measurements obtaining a good localization of an inclusion within the reconstructed volume.

The performed phantom measurement is paradigmatic of what happens during a brain activation where a deep and localized variation in oxygenation can take place, thus reflecting into a variation of the tissue optical properties. We are currently running a comprehensive characterization of the systems and planning *in-vivo* measurements to validate the suitability of this system for clinical applications such as brain imaging.

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