Portable system for Time-Resolved Near-Infrared Spectroscopy

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The interest in non-invasive optical monitoring techniques is growing in several fields (e.g. biomedical, pharmaceutical, agricultural and chemical industries). Diffuse optics investigates photon propagation phenomena in highly scattering media, recovering information about their optical properties [1]. In Time-Resolved Near-Infrared Spectroscopy (TR-NIRS), picosecond light pulses are injected into the sample and diffused photons are collected (at a certain distance from the injection point) by means of time-resolved single-photon detectors, measuring their arrival times. TR-NIRS is able to retrieve more accurate information from deeper sample layers compared to other approaches (e.g. Continuous Wave) and has the capability of measuring absolute optical parameters, also exhibiting lower artifacts sensibility [1]. This is achieved thanks to the natural disentanglement between absorption and scattering phenomena and the strong relationship between sample penetration depth and photon arrival times. In the biomedical field, the demand for monitoring and imaging instrumentation based on TR-NIRS is constantly increasing in applications like functional brain imaging, muscle oximetry, optical mammography. Up to now, most of TR-NIRS instruments are custom-made prototypes based on commercial components [2], thus intrinsically exhibiting scalability problems, high complexity and high cost.

Trying to answer to this demand, we present a portable full-custom TR-NIRS instrument, developed starting from years of research activity on diffuse optics and dedicated hardware at Politecnico di Milano. Fig. 1 shows the simplified block diagram of the system, which includes all the fundamental building blocks of a complete TR-NIRS setup, with extremely compact dimensions (200×160×50 mm^3) and weight (~ 2.5 kg) [3]. It includes: i) two compact pulsed laser sources (at 830 and 670 nm wavelengths) based on gain-switched laser diodes, able to deliver optical pulses having duration shorter than 250 ps with up to 3 mW of average optical power (at 50 MHz repetition rate); ii) a photo-detection module, based on a 1.3×1.3 mm^2 area Silicon Photomultiplier (SiPM), custom designed to optimize its single-photon timing performance; iii) a system control board, also integrating the time-measurement electronics based on a custom Time-to-Digital Converter (TDC) having 10 ps temporal resolution and 40 ps single-shot precision. The instrument is able to directly acquire the Distributions of Time-of-Flights (DTOFs) of photons emitted from the tissue under test. Data is transferred in real-time to the embedded computer via a USB link for data analysis and recording. The system can be battery operated and remotely controlled, ensuring several hours of operation. Characterization on solid phantoms and results obtained from in-vivo measurement campaigns (especially on-field, like the oximetry measurement in Fig. 2, acquired during a bicycle exercise), have shown the excellent performance of the instrument [4] which, thanks to its portability and ease of operation, can pave the way towards the diffusion of time-resolved NIR spectroscopy.

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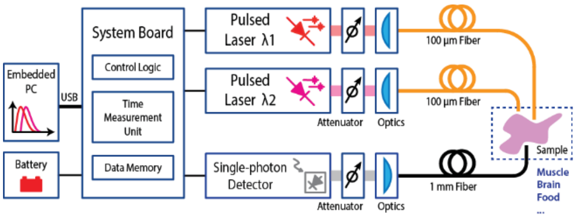

Fig. 1 : Simplified block diagram of the instrument, composed by two pulsed laser sources and a time-resolved single-photon detection channel, based on SiPM and 10-ps resolution TDC. Battery operation ensures several hours of on-field measurements.

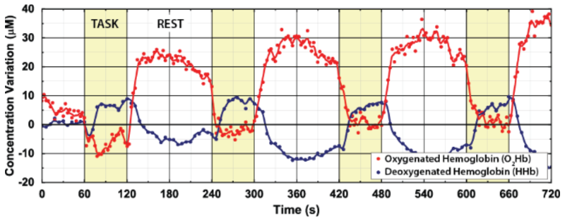

Fig. 2 : Oximetry measurement on the right-leg vastus lateralis during a bicycle riding exercise (4 repetitions). The instrument is worn by the subject as a backpack. Variations are calculated respect to values measured before starting the exercise.

References

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