

# A compact dual-channel system for time-domain NIRS spectroscopy of muscle and brain

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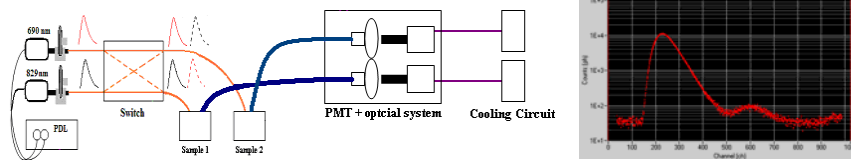
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## INTRODUCTION

Several multichannel systems for time-resolved NIRS have been reported in literature (M. Wolf *et al.* J.Biom. Opt. 12(6):2104, 2007) and successfully used for imaging studies, there are clinical applications where an instrument with a limited number of channels can be effectively used for monitoring pathophysiological changes. For example in motor rehabilitation of stroke patients, we have employed time-resolved NIRS to quantify the progress of training protocols by measuring the muscle hemodynamics with one optode on each leg (S. Ferrante *et al.* J.Biom. Opt. *in press*). The use of a limited number of channels moreover reduces the size and the cost of the instrument.

In this work, we present the development of a compact two wavelengths and two channels time-resolved NIRS system. This kind of system can't be used to perform imaging studies but is adapt to clinical monitoring of tissue oxygenation during muscle rehabilitation and to monitoring patient during treatment (e.g. in intensive care). The system is based on a novel approach consisting of space-multiplexing of the two wavelengths.

### SYSTEM SET UP

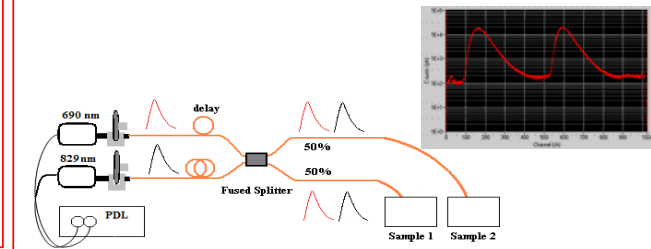


A couple of pulsed diode lasers (690 nm and 829 nm, 80 MHz repetition rate, 1 mW average power; PDL, Picoquant GmbH, Germany), is used as light sources. The laser heads are connected to multimode graded index fibers (50/125  $\mu\text{m}$ ) by means of a custom-made coupler which combines a neutral density attenuator (NT43-770, Edmund Optics GmbH, Germany), with variable attenuation in the range 0-80 dB, and a standard FC fiber optics coupler. A stepper motor (440-436, RS Components, Italy) is used to automatically control the variable attenuator. Before going into the sample, light pulses, go through the optical 2X2 switch (LEONI Fiber Optics GmbH, Germany). Collection of remitted photons after migration in the diffusive medium is provided by two fiber optic bundles (Loptek Glasfasertechnik GmbH, Germany), with total dimension of 3 mm. After the bundle, signals are attenuated by a system similar to the one in the acquisition section and coupled to the cooled photomultiplier tubes (PMC-100, Becker&Hickl, Germany) with a proper optical system. The acquisition of time-resolved reflectance curves is accomplished by 2 parallel and identical boards (SPC130, Becker&Hickl, Germany) for time-correlated single photon counting (TCSPC) hosted in a PCI-box (PCI-Cardbox 2F, IBP Instruments GmbH, Germany) interfaced with a laptop.

### SPACE-MULTIPLEXING

The novel approach, we have developed, is based on space-multiplexing of the two wavelengths. By means of an optical 2X2 switch, the two wavelengths are injected alternatively in the two channels. In this way, we can acquire, in each detection line and in each temporal window, one wavelength, in order to exploit the full temporal and dynamic range of the acquisition boards. We can perform measurements with two independent but temporally parallel channels. The disadvantage is that the two wavelengths are not simultaneously measured in the same point. This problem is overcome by using an elevated switching rate, so that hemodynamic changes during brain activation or muscle work can be followed with acquisition times less than 1 s.

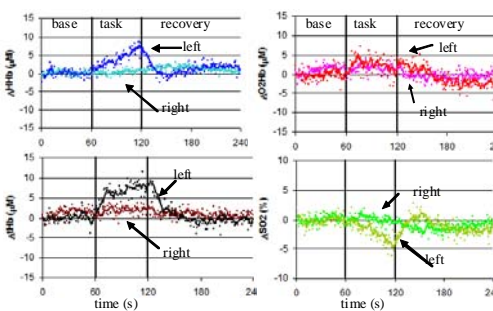
### TIME-MULTIPLEXING



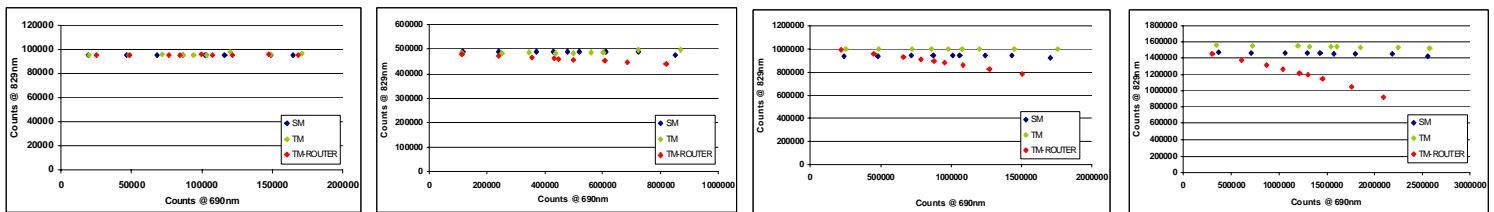
The optical pulses at different wavelengths are delayed one respect to the other by optical fibers of proper length. Then, a fused splitter is used to time-multiplexing the laser pulses at the two wavelengths. In this way measurements are performed simultaneously at the two wavelengths, but problems of crosstalk between the pulses might hamper the overall performance of the system. A first source of crosstalk could be the superposition in time of the DTOFs. A second source of crosstalk might arise from significant changes in the count rate of one of the wavelengths. This is more crucial when the count rate is high. Therefore to minimize the crosstalk it is necessary to keep low the count rate with an overall reduction of performances.

### IN VIVO MEASUREMENTS

Preliminary *in vivo* measurements are presented to show the use of the system for tissue oximetry studies. We simultaneously investigated the right and left arm, on each of which we arranged one source and one detector at a relative distance of 2 cm. The protocol consisted in 60 s baseline, 60 s task (arterial occlusion on the left forearm muscle) and 120 s recovery.



### SPACE- and TIME-MULTIPLEXING COMPARISON



We compared three different modality to perform measurements: the time-multiplexing (TM) the space-multiplexing (SM) and the space-multiplexing modality with the introduction of a router, necessary to increase the number of the detection channels. We performed measurements keeping one wavelength at a fixed value (100K, 500K, 1000K, 1500K Counts) and varying the value of the other wavelength from -75% and +75% of the constant value. The results show that there are no significant difference, in terms of counts, between the system using the TM and the SM modality. The difference is clear when we introduce the router. In fact the router doesn't allow us to perform measurements with high value of counts of either wavelengths.