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Characterization and in-vivo DCS measurements with compact 1064 nm laser

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Abstract: We investigated a 1064nm compact laser as a potential TD-DCS source. Through BFI stability measures, studies on phantoms of varying viscosity and an in-vivo measurement we found that it is sufficiently accurate for future work.

1. Introduction

Time Domain Diffuse Correlation Spectroscopy (TD-DCS) is a novel technique that uses pulsed lasers to analyse non-invasively the blood flow in biological tissue at a selectable depth [1]. This technique is a modified version of the already commonly used Continuous Wave Diffuse Correlation Spectroscopy, which serves medics in hospitals to monitor in real-time the blood flow in the brain of patients [2]. The addition of depth-selectivity for TD-DCS allows an improvement in signal to noise ratio, especially by reducing the influence of skin blood flow.

For an effective use of this technique a laser with high coherence but short pulses is required. We investigated a laser that has a power output of 1.2W with a tuneable pulse repetition rate and temporal pulse width [3]. It has high coherence capable of generating auto-correlation curves with a beta value of around 0.3 and pulses in the range of 100-500ps. The laser size is considerably smaller than a typical Ti:Sa laser setup, which has been used for similar works on TD-DCS [4], making it more easily transportable to a hospital for medical applications in the future. It also operates at 1064nm (instead of the typical 765 to 850nm) which is advantageous for this technique for three reasons: firstly in the infrared range there is a local minimum of water absorption at this wavelength permitting more signal to travel around the biological tissue and come back to the detection fibre. Secondly, according to ANSI standards, this light is less harmful to human skin so more power can be utilized when performing in-vivo measurements. Third, 1064nm light has a greater quantity of photons for a given amount of energy, allowing up to 13 times higher overall detection rates [5].

Before doing a full Time Domain study, this work investigates the properties of this laser to establish its overall suitability for future works.

2. Method

2.1. *Experimental setup and task description*

To investigate the compatibility of the laser with TD-DCS we carried out 3 experiments: a 10 minute stability study at 10 different parameter combinations, a study of phantoms with varying viscosity at the optimal parameter combination and an in-vivo cuff occlusion measure.

All these experiments were carried out with the Manny laser (Irisiome Solutions, France), a Superconducting Nanowire Single Photon Detector (SNSPD) (Single Quantum, the Netherlands) and the electrical signals were recorded by a Time Tagger X (Swabian Instruments, Germany).

In the first part we studied the optimal parameter combination due to the tuneability of this laser by using liquid phantoms made of water and intralipid 20% [6], and instead of the blood flow we measure the Brownian motion coefficient D_b. We took 10 minute long measurements with the following settings: 100ps, 200ps, 300ps, 400ps and 500ps pulse widths done once at 100MHz and once at 10MHz repetition rates. We looked at how precisely the D_b value was being measured, telling us what parameter combination is most stable for experiments.

In the second part we verified the accuracy of the system by studying liquid phantoms with varying concentrations of glycerol (and therefore varying viscosity) and comparing the resulting Brownian motion coefficient D_b with the theoretical expectation:

$$D_b = \frac{K_b T}{6\pi r v}$$

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where K_b is the Boltzmann constant, T is temperature, r is the radius of the Brownian particle and ν is the viscosity coefficient. We studied the following concentrations: 0%, 10%, 20%, 30% and, to obtain the viscosity coefficient for each, we used the data provided in [7].

In the third part we studied the change in blood flow in the forearm of a healthy volunteer due to an increase in pressure of a cuff around the bicep. We measured the baseline blood flow for 5 minutes before increasing the pressure of the cuff to 250 mmHg for 5 more minutes, and then monitored the blood flow for a further 5 minutes after releasing the pressure in the cuff. The subject gave his written informed consent and experiments, approved by the Ethical Committee of Politecnico di Milano, were conducted in compliance with the Declaration of Helsinki.

All these measurements were carried out with a fixed source-detector separation of $1.5cm$.

2.2. *Data analysis*

The measurement outcome for each experiment is a data file with the arrival times of all detected photons with an accuracy of a few picoseconds. To determine the blood flow (or D_b) we carried out an autocorrelation calculation with this data. The decaying curves resulting from this analysis are then fitted with $Ae^{-\alpha D_b \tau}$. Successively, αD_b was retrieved from the measured intensity autorcorrelation curves by fitting the data to the solution of the correlation diffusion equation for a semi-infinite homogeneous medium [8].

For the first and second part of this investigation, we have 10 minute long measures. The data for each measure was split into sections lasting 20 s, then analysed individually to obtain a value for the Brownian motion coefficient D_b. That yielded 30 data points from which we derived the mean value and standard deviation (as a percentage of the mean value). For the third part, the 15 minute long cuff occlusion was split into 1 s sections to yield 900 data points, all included in the final plot.

3. Results

In the first part of the investigation each 10 minute measurement resulted in a percentage error for each parameter combination as can be seen in Table 1.

Table 1. D_b values with percentage standard deviation obtained for each combination of parameters for 10 minutes on a liquid phantom.

(Units: $10^{-9}\text{cm}^2/\text{s}$)	100MHz	10MHz
500ps	2.16 +/- 0.90%	2.48 +/- 1.27%
400ps	2.11 +/- 0.75%	2.44 +/- 0.96%
300ps	2.05 +/- 0.70%	2.40 +/- 1.09%
200ps	2.01 +/- 0.84%	2.32 +/- 0.87%
100ps	1.96 +/- 1.06%	2.29 +/- 1.16%

All parameters show stable values with small errors less than 1.3%. To make a compromise between the pulse duration and coherence length we chose to set the parameters to 100MHz and 300ps for the rest of this study.

In the second part of the investigation the measured D_b successfully matches the theoretical expectation of $D_b = K_b T / 6\pi r \nu$ as can be seen in Figure 1. This result confirms the sensitivity of our system to changes in the measured sample, demonstrating it can be used to obtain accurate information.

In the third part we also successfully obtained the expected behaviour for the blood flow in a cuff occlusion experiment as can be seen in Figure 2. The relative BFI increases by roughly 700% with respect to the baseline level once the cuff occlusion is released and it takes roughly 100 seconds for the levels to go back to baseline.

4. Conclusion

The technology on which the laser here employed is based resulted to be suitable for experimental use in the field of TD-DCS and Time Domain Speckle Contrast Optical Spectroscopy (SCOS). It was shown to yield good results in terms of accuracy and precision. Further work should first aim to evaluate the collected data in a depth-selecting way and, even further, aim to utilise this laser source for in-vivo studies on other areas such as eggs or the human brain to investigate the advantages of Time Domain DCS over the alternative Continuous Wave DCS with a full Time Domain analysis.

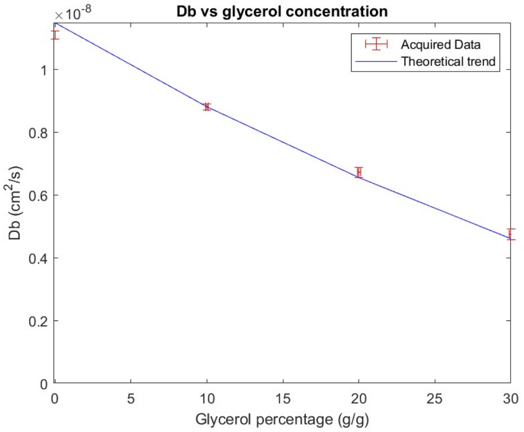

Fig. 1. Plot of D_b vs glycerol concentration in the liquid phantom (to vary the viscosity) examined with the laser set to 100MHz, 300ps. It can be seen that the experiment matches well with the theory.

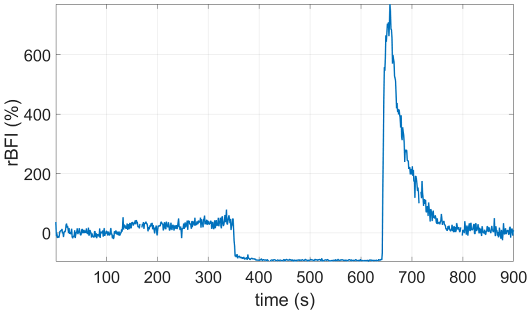

Fig. 2. Plot of the relative change of blood flow index in the forearm of a patient undergoing a cuff occlusion (performed from t = 350s to t = 650s).

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