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Development of a hyperspectral time resolved DOT system for the exploration of the human brain activity

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Abstract – Diffuse optical tomography (DOT) is a growing area of research in the field of biomedical optics and neurosciences. Over the past 20 years, technical development allowed a more and more accurate detection of the brain activation.

In order to increase the accuracy of the brain's activation detection, we have developed a Hyperspectral Time Resolved DOT system. It is composed of a compact supercontinuum laser within the picosecond range for the source part and of an ICCD camera coupled with an imaging spectrometer for the detection part. This allows a simultaneous detection of the spatial, time resolved, and spectral information.

Through the information acquired by our system, we can propose a method that increases the accuracy of the optical imaging of the cerebral activity, both spatially and in term of specificity, by obtaining its broadband optical characterization. On top of the improvement of the accuracy of the detection, the compact size of our system has the great potential to be easily transport in a clinical environment.

Index term - Biophysics, Image Processing, Optical Imaging.

I. INTRODUCTION

Functional neuroimaging technics is now an essential tool for physicians and researchers. This tool allows neuroscientists to better understand the brain's function and physicians to improve the clinical management of patients. In order to do so, several imaging techniques are available. One can cite fMRI, PET, EEG, MEG, and Diffuse Optical Tomography (DOT) [1].

Actually, beside the other well establish techniques, Diffuse Optical Tomography is an area of growing interest. Even if its practice is still not well developed yet in clinical applications, it is more and more used in the neurosciences field. Indeed, there are a lot of advantages with this technique. The most significant is the portability and the fact that the subject can move freely while being scanned, which is a tremendous advantage in a lot of applications for which fMRI can't be used. The second characteristic, which is of great interest, is the fact that theoretically the DOT can monitor both hemodynamic

and neuronal responses together, with only one instrument. Over the past 20 years, the technical developments in DOT allowed a more and more accurate detection of the brain activation, both spatially and in the calculation of the variations of chromophores's concentrations such as Hemoglobin, cytochrome c oxidase, etc...[2] . Besides those advantages, one of the main issues of this technique is the difficulty to separate the systemic response due to the skin from the response of the brain due to the activation itself. This problem can be reduced by using time resolved instruments which are much more precise than the Continuous Wave systems commonly used in optical neuroimaging [3]. Those systems record the arrival time of photons, which codes directly the depth of penetration of the photons. Then by distinguishing the early from late photons, one can separate deep from superficial tissues. Thus, this technique has the potential to separate the superficial from deep layers. Although one can distinguish between those deep and superficial tissues, no absolute correspondence can be done between the arrival time of photons and the real penetration depth.

In order to increase the quality of the discrimination of the tissues and the accuracy of the brain's activation detection, by obtaining its broadband optical characterization, we propose a Hyperspectral Time Resolved DOT system.

II. MATERIALS AND METHODS

We developed a system composed of a compact supercontinuum laser within the picosecond range for the source part and of an ICCD camera coupled with an imaging spectrometer for the detection part. This allows a simultaneous detection of the spatial (up to 70 reception points), time resolved (minimum gate width 200ps, minimum delay shift 10ps), and spectral information (from 500 to 900 nm). A scheme of the system can be found in figure 1. The output beam of the laser is first filtered to have a spectrum between 500 and 900 nm. It is then injected in a fiber to illuminate the head. The filtered beam is also monitored with a Photodiode (PD) to check for the output power stability. Then an array of optical fibers is arranged all around the source in order to conduct the retro-diffuse signal to the detection part.

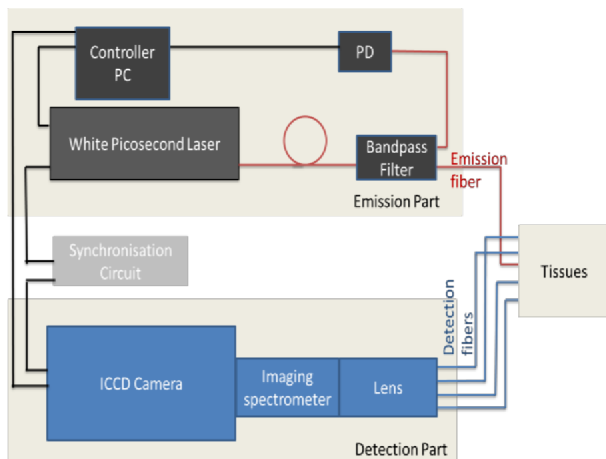


Figure 1: scheme of the system.

We then performed the measurement of a sequence of activation on a healthy subject involving the prefrontal cortex. The subject was asked to perform a simple calculation task.

The measurement was performed in two steps. First the data were acquired for the static condition, when the subject was asked to stand still. Then, by fitting the spectra acquired in this condition to a set of reference spectra of basic components of tissues (HB, HBO₂, water, etc...), we could estimate more accurately the type of tissue probed as a function of the time delay. Then after identified the best arrival time of photons for probing the brain, we performed the recording of the activation sequence.

III. RESULTS

We have developed and characterize a new DOT instrument that brings together the spatial, spectral a time resolved dimensions. With this system we could retrieve the cerebral activity as the result of a specific cognitive task, by detecting the hemodynamic signal. This signal can be seen on figure 2.

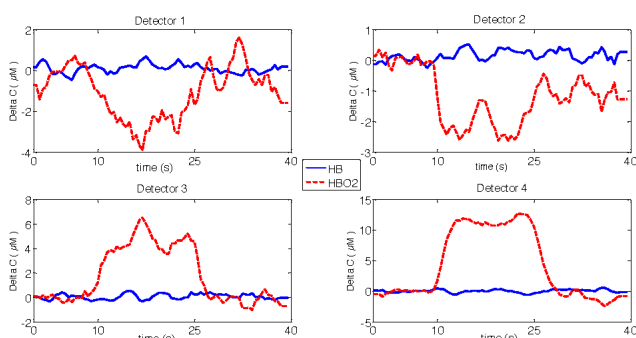


Figure 2: Hemodynamic signal of the human brain activity for four detectors on the forehead.

IV. DISCUSSION – CONCLUSION

We have developed a system that is increasing the amount of information about the brain's activation. First it improves the distinction between superficial and deep layers, by fitting the static image to extract the composition of tissue probed and retrieved the best windows for probing the brain. Then it allows retrieving the hemodynamic signal together with the first spectrum of the physiology of the human brain activation which can help to distinguish this signal from the neuronal one.

Indeed, beside the hemodynamic response, optical signal have also been reported to bring information about neuronal activity itself with the Event Related Optical Signal, although this signal is still controverted [4]. We believe that the characterization of the spectral response of the hemodynamic response will be helpful to dissociate those two contributions in order to retrieve the hemodynamic response on the one hand and the EROS signal on the other hand.

In conclusion, the developed a Hyperspectral Time Resolved DOT system is increasing the accuracy of the detection of the human brain activity via optical techniques. This system allowed us first, to better locate the brain's region to separate systemic from physiological response and then, to acquire the first spectrum of the physiology of the human brain activity. This system will also be useful for the detection of the EROS signal.

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