

Near Infra-Red Spectroscopy: a low cost device

Peter Rolfe^{1,2}, Giovanni Mondo¹, Fabio Bottini¹, Davide Repetto¹, Carmelina Ruggiero¹

¹ Department of Informatics, Systems and Telematics - University of Genova, Genova, Italy

² Oxford BioHorizons Ltd, Shropshire TF9 2QW, Marker Drayton, UK

Abstract

In vivo near infra-red spectroscopy (NIRS) is based on interrogation of tissue with light, a non invasive measurement. Penetration with near infra-red wavelengths in tissues is greater than with visible light, and specific absorption by compounds relevant for diagnosis and monitoring enable safe and convenient in vivo measurement. NIRS can be used for the early diagnosis of cerebral pathologies of vascular origin, cortical blood flow monitoring and the analysis of cortical activity.

Recent advances in microelectronics make it possible to build small, portable, low-cost NIRS instruments capable of measuring chemical compounds relevant for diagnosis and monitoring.

We have developed a low cost NIR module to be used for spectroscopy and imaging.

This device is based on emitter-detector modules using laser diodes and PIN photodiodes, overcoming disadvantages of vacuum photomultipliers, and obviates the need for optical fibre connection. We have used intensity modulation with spatially resolved measurements. For measurements of (O₂Hb) and (HHb) two wavelengths are sufficient. For each of them we measure demodulation and phase shift and hence the absorption coefficient and the reduced scattering coefficient, from which chromophore concentrations can be determined.

Detector signal analysis and sequentially controlled switching is achieved using a Pentium III computer.

The module has a cost below a few hundreds US dollars and it is quite small, and can be used for cortical oxygenation maps.

Introduction

Optical methods and devices are being used for a variety of biomedical applications since the last twenty years. Instruments based on the use of visible light have been used for chemical analysis - colorimetry and spectrophotometry - since the nineteenth century, and now it is possible to quantitatively analyse liquid samples in the laboratory. More recently instruments for direct chemical analysis in tissues were developed, and at the beginning of the twentieth century instruments based on the use of visible light began to be used.

Subsequently, it was found that the near infrared part of the spectrum was capable of deeper penetration of tissues than is possible with visible light. Since then, in vivo NIR

spectroscopy (ivNIRS) was developed, and this method allowed to achieve safe and non invasive monitoring of important variables in a variety of clinical applications. NIR light in the spectral window ranging from 650 nm to 1200 nm can penetrate tissues up to several centimeters, which makes it possible to measure optical properties of several organs.

The first field in which ivNIRS was used is oximetry, for both invasive and non invasive measurement of blood oxygenation.

Hemoglobin can exist in two main forms, oxyhemoglobin (O₂Hb) and deoxyhemoglobin (HHb), with different specific optical absorption characteristics.

NIR spectroscopy has been found to be able to measure oxygen dependent chromophores, that is chemical compounds that absorb incident light. According to Lambert-Beer's law in solutions of one substance the attenuation (logarithm of the ratio of the incident light and of the transmitting light) is proportional to the product of the concentration of the substance, the molar extinction coefficient and the light pathlength. It has been found that water does not contain chromophores in the NIR region, therefore the concentration of the substance coincides with the concentration of chromophores. In experiments in vitro only one substance in solution is considered, therefore only one chromophore type is present, so the scattering and adsorption is the same for all chromophores (fig. 1). In vivo different chromophores are present, therefore scattering and absorption are different for different chromophores (fig. 2).

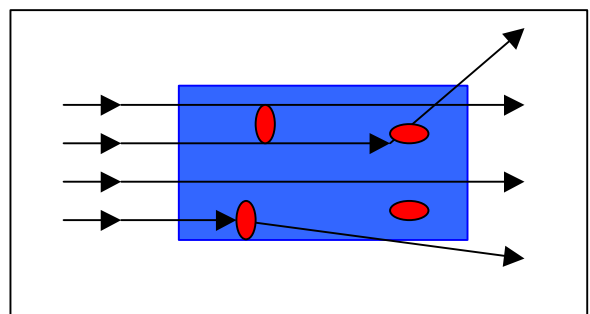


Figure 1: In vitro scattering and absorption due to one kind of chromophores only.

Report Documentation Page

Report Date 25OCT2001	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Near Infra-Red Spectroscopy: a low cost device	Contract Number	
	Grant Number	
	Program Element Number	
Author(s)	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) Department of Informatics, Systems and Telematics - University of Genova, Genova, Italy	Performing Organization Report Number	
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development and Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	Sponsor/Monitor's Acronym(s)	
	Sponsor/Monitor's Report Number(s)	
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes Papers from the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001 held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 3		

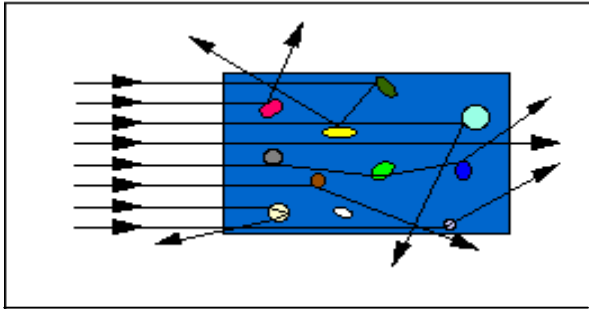


Figure 2: In vivo scattering and absorption of light due to various chromophores.

The aim of the present work is to realise an efficient low-cost module for monitoring local physiological parameters to be used in a portable imaging system. The system which has been designed is mainly based on solid state devices, integrated relays and a personal computer for data acquisition and processing.

Methods

Chromophore concentration can be determined using basically three methods: the spatial resolution method, the time of flight method, the frequency domain based method. The spatial resolution method allows to measure the concentration of hemoglobin and uses the information obtained from the variation of intensity of the retro-reflected light as a function of the distance between the source and a series of equally spaced detectors. The time of flight method allows to calculate the average pathlength of the photons generated by an impulse inside the tissue estimating the instant in which width of the point spread function is maximum. The frequency domain method evaluates the adsorption coefficients of the chromophores from measurements of the phase variation and amplitude of a light signal modulated in a radio frequency which is applied to the tissue. For this initial prototype we have adopted the frequency domain based method. Each of the module we have designed consists of two laser diodes and of a Positive Intrinsic Negative (PIN) photodiode. The laser diodes, which emit in two different NIR wavelengths, are very inexpensive, have a large bandwidth and may be modulated at high frequency. PIN photodiodes have a very high sensitivity and their cost is about a quarter of PMTs. Two lasers are enough to measure two chromophores, specifically oxy and deoxy haemoglobin. The two lasers are modulated in very low frequency sequentially by a switcher. The input and the detected signals are both shifted in low frequency, by demodulation, and their phases and amplitudes are compared with the source. From these quantities it is possible to determine the relative chromophore concentrations. A scheme of the system is given in fig. 3.

The prototype with low frequency fig. 4 (page 3) consists of two circuits: one includes the amplifier of the signal from the oscillator coming, two led diodes, the micro deviator which achieves channel separation and the component which generates the reference signal. The other circuit includes the photo diode for collection from transmitted light, signal amplification mixing and final filtering.

Figure 5 shows the final device consisting of two modules, the transmission module and the reception module. The lower part of the figure shows the model that performs heterodyne demodulation of the reference signal.

III. RESULTS

A schematic diagram of the system developed is given in Figure 3.

Two wavelengths are used to measure two chromophores, specifically oxy and deoxy haemoglobin, $[O_2Hb]$ and $[HHb]$. The two lasers, emitting at 850 nm and 780 nm, are switched sequentially at around 50 Hz. The intensity of one laser is modulated at 80.000 MHz and that of the second at 80.001 MHz. At present the module has been assembled and its dimensions are about 13x7x3cm using dual-in-line package integrated circuits.

The PIN photodiodes have a very high sensitivity, they are pre-amplified and have a very small active surface (100 μ m in diameter) that allows high speed. Their cost is about a quarter of PMTs. Two receiver switchers are synchronised with the transmitter at the 50 Hz switching frequency. The transmitting and receiving cross-correlation frequencies of 1 kHz are used to derive information on phase shift (ϕ_{780nm} , ϕ_{850nm}) and demodulation ratio (Mac_{780nm} , Mac_{850nm}).

The outputs of the physical system, the phase shifts and the demodulation ratio at the two different wavelengths, are digitally converted by an acquisition board and processed by a Pentium III based personal computer. The chromophore concentrations are then determined using a solution of the diffusion equation [i]. Data are collected and shown in graphs and maps by a user friendly interface based on LabVIEW™ platform. This platform has the advantage to be easy to use and allows users to personalise output and compare the results with other methods.

In order to test and calibrate the whole system *in vitro* a cuvette filled with blood cells in distilled water has been used. The instrument has been calibrated with different oxygen concentrations. Test results have been compared with those obtained using Monte Carlo simulations [ii] obtaining a reasonable validation.

IV. DISCUSSION

Our approach allows the application of the transmit-receive modules directly to the skin avoiding the use of optical fibers. This system is practice, portable and has low costs. Moreover a modular, solid state approach

with Surface Mounted Devices or custom chips would allow cortical oxygenation maps to be obtained with 64 or more probes. Such a NIR device could be useful and cheap compared with 3-D NIR imaging systems envisaged.

V. CONCLUSIONS

The philosophy of designing a low-cost NIRS instrument appears to be viable. Our future efforts will be oriented to optimise module performance, to increase S/N ratio, and to improve user interface. Moreover, we will combine the frequency domain method with the spatially resolved method. This allows to estimate absolute concentration of oxy and deoxy haemoglobin.

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