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Development of an autonomic portable single-board computer based high resolution NIRS device for microcirculation analysis

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Abstract—**Near Infrared Spectroscopy (NIRS) is a well-established non-invasive technique for measuring metabolic changes in biological tissue. In this paper we describe the design and development of an autonomic portable single board computer based high resolution NIRS device, which allows quantification of these changes. The sensor-patch consisting of 8LEDs and 2photo-detectorsprovides8 channels for each detector, offering increased depth resolution for monitoring microcirculatory activity..NIRS data is acquired with a sampling rate of about 2Hz per channel using the data acquisition board which consists of a 16 bit ADC, a LED driver and programmable gain amplifiers. The components on the data acquisition board are controlled via the Advantech's PCM-3355L SBC based on Windows XP platform. The software was created using Visual Basic 6.0 and Microsoft Visual C++ 6.0. It offers optionally a real time 'monitoring' and a static data (off-line) visualization mode. The most unique feature of the system is its ability to auto-calibrate itself i.e. Adopt the intensity of the LEDs output light to different experimental conditions, e.g. local melanin content, density of the tissue, and emitter-detector distances. To validate the device various experiments have been carried out such as measurements on resting and working gastrocnemius and biceps muscle in ambulatory situations. The achieved results confirmed adequate performance and reliability of the device.**

I. Introduction

Monitoring the changes in local microcirculation in response to adequate stimuliis gaining importance in modern healthcare, since pathological deviations often manifest themselves as malfunction in microcirculation. Microcirculation monitoring is usually carried out by measuring concentration changes of various chromophore, which have a close relation to the underlying tissue functionalactivity.NIRS is one of the emerging non-invasive techniques, which takes advantage of the relative transparency of body tissues for the NIR region of the spectrum. This transparency is observed mainly in the range of 650-900nm due to the relatively low light-absorption by water and hemoglobin. This makes the wavelengths suitable for monitoring microcirculatory tissue activity [1].

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The interaction between NIR light photons and body tissues is quite complex due to absorption and scattering, which in effect alters the trajectories of the photons [2] [3]. Current NIRS instruments are designed to capture these interactions thereby quantifying the concentration of oxy- and deoxy-hemoglobin ($HbO_2$and Hb) present in tissue [4]. Applications of NIRS systems for research and clinical purposes are pre-surgical diagnostics simultaneously with EEG, in patients suffering from refractory epilepsy, studies of spatial-temporal changes in the oxygenation of muscles etc.[5][6][7].NIRS has extensively been used in Diaphanography, a technique for breast tissue imaging applying NIRS in trans-illumination mode [8].

The use of NIR light for non-invasive monitoring of changes in microcirculation was invented by Jobs in 1977.Since then different NIRS devices have been developed [9]. Zhang Y. et al. have presented a portable ARM processor based NIRS device, with limited resolution of only one channel [10]. Rolfe P. et al. have also developed a low cost NIRS instrument using PIN diodes; however, this needs a Pentium III computer for control and signal analysis [3]. Chen W. et al. has designed a smart NIRS device in which the sensors could be coupled to the body through holes inside the clothes [11].

In this paper we present a portable, stand-alone and high resolution NIRS device. We describe its design and development based on the Windows XP platform and an Advantech's PCM-3355L PC/104 standard single board computer (SBC) for monitoring microcirculatory activity of tissues. The sensor patch consists of photodiodes and dual-wavelength LEDs with high coupling capability.

II. Theoretical Background

A. Optical Properties of Tissues

Propagation of photons through biological tissue is mainly affected by three photo-physical processes: refraction, scattering and absorption [12]. Refraction of light occurs due to different refractive indices of the materials through which light travels. Scattering is reflection at a surface present in a localized area within the medium of interest [13]. Among the abovementioned photo-physical processes, absorption is the most important phenomena utilized in NIRS instruments. During absorption molecular species extract energy from the passing light [12]. The quantifying property is the absorption coefficient μ_a which is the average distance travelled by photons before absorption [13].

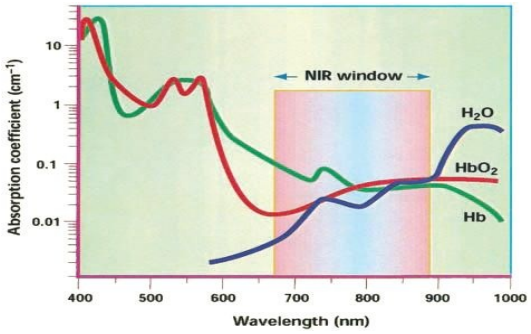

Figure.1. Absorption spectrum of HbO_2, Hb, andwater (H_2O) [4].

The main chemical species here of interest are HbO_2 and Hb. These important chromophore of the biological tissue have both a low absorption for wavelengths in the range of 650-900nm. This is the so called 'Optical Window' which allows light to penetrate deeper into the tissue [4]. The absorption spectra of the main chromophore of the blood are shown in Fig.1

B. Modified Beer-Lambert's Law

Relative changes in concentration of Hb and HbO_2 for an attenuating medium are given by the Modified Beer Lambert's Law (MBLL)[4]. According to the MBLL, the absorbance A or optical density OD is given by:

$$A = OD = \log (I_0/I) = \varepsilon.C.L + G \qquad (1)$$

where, I_0 is the incident light intensity, I is the detected light intensity, ε is the extinction coefficient, C is the concentration of a particular chromophore, L is the path-length of the light through the sample and G is a factor concerning tissue geometry [2][10][16].

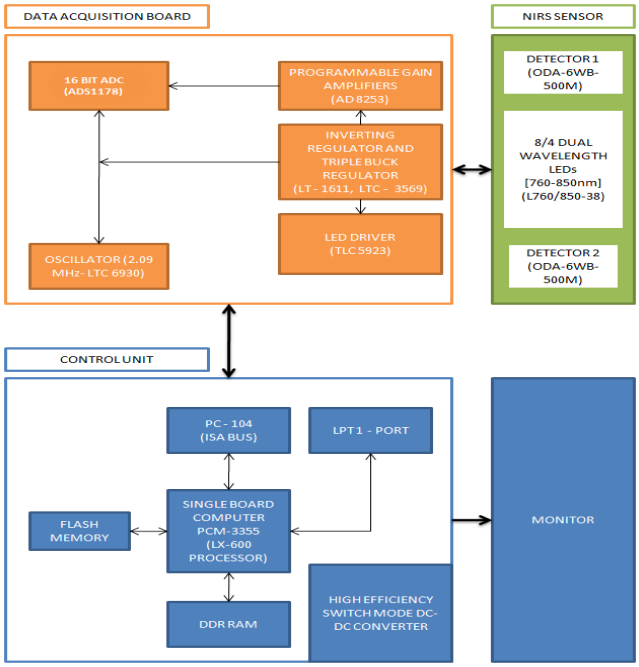

Figure.2. System block diagram.

III. HARDWARE DESCRIPTION

The SBC based portable NIRS system consists of three main blocks: the signal acquisition patch, the data acquisition board and the control/processor unit. The sensor-patch carries flexible silicon slice eight NIR LEDs and two photo-detectors (PD) with integrated preamplifier. It can be easily positioned anywhere on the body adapting perfectly to varying surface geometry. Signals acquired using this patch is then transferred to the data acquisition board, which does signal conditioning and A/D conversion. The data are then sent to the control/processor unit for further processing. This unit is an Advantech's PCM-3355L SBC with an embeddedLX-600 processor, which runs on windows XP. The processing, monitoring and controlling software are coded in Visual Basic V6.0 and Visual C++ V6.0. The basic system block diagram is shown in Fig.2.

A. Single Board Computer

The PCM-3355L SBC has a performance fulfilling the demands for the development of a portable NIRS system. It offers LPT, USB, Serial and PC/104 interfaces, hence providing all possibilities to realize an autonomic signal acquisition and processing system.8-Channel NIRS patch.

B. NIRS sensor-patch

The emitters are 8 dual-wavelength (760nm and 850nm) L760/850-38 NIR LEDs from "Meuvo-Technik",which have been found to be optimal concerning separability, cross talk and market availability. The detectors are two PDs, ODA-6WB-500M from "Opto-Diode Co." with integrated preamplifier. All components have been embedded in a silicone patch, whose dimensions have been chosen based on the physical dimensions of emitters and detectors with the aim to achieve high spatial resolution. Therefore the detector is positioned at a distance of 10mm from the first emitter and the distance between consecutive emitters is 5mm. This should provide a hardware basis for further development and application of algorithms for spatial depth resolution. The patch is connected to the data acquisition board by a flat cable. The sensor patch has been created in two steps embedding the hardware components in polymerizable liquid silicon; Fig.3shows the 8 dual-wavelength LEDs positioned between the PDs. The connecting flat band cable is visible on the left.

C. Data Acquisition Board

The data acquisition board is designed and developed in accordance with the PC/104 standard so it can be stapled over the SBC. It has a LED driver, TLC5923 from "Texas Instruments" to control the intensity and the sequential on/off

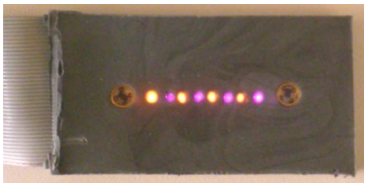

Figure 3.8-Channel NIRS patch

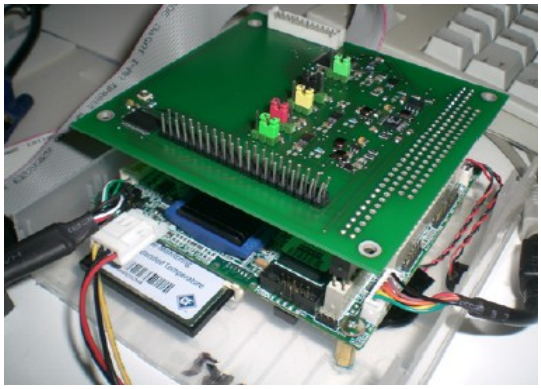

Figure.4. Data acquisition board stacked over the PCM-3355L SBC

Switching of the LEDs. The LED driver can set the intensity of each LED individually to 128 different levels. The PD detects the backscattered light and its integrated trans-impedance amplifier converts its output to voltage. Since a photovoltaic configuration has been used in conjunction with the PD with 500MΩ feedback resistor and integrated preamplifier, this detector offers an extremely low-noise with high gain (250V/μW). Thus it is well suited for detection of low-level back-scattered photons. The outputs of the PDs are then amplified by two programmable gain amplifiers, which can amplify the voltage levels by x1, x10, x100 or x1000. This is of importance when the region of interest is placed relatively deep in the tissue.

The board contains in addition the "Texas Instruments" ADS1178, a 16 bit A/D converter, which converts the analog signals simultaneously to digital data. In the Standard Parallel Port (SPP) mode the LPT1 port operates as a bidirectional interface by sending Graphical User Interface (GUI) generated control signals to the different components on the board, while receiving from them the acquired data. The data acquisition board is stacked over the SBC using the PC-104 port as shown in Fig.4.

IV. Software

The GUI has been developed in Visual Basic 6.0 and the dynamic link libraries (DLL) were written in Microsoft Visual C++ 6.0. It includes features such as real time online and offline visualization of raw and processed data (Hb and HbO_2). In the real time data mode, the data is acquired and displayed with a sampling rate of 2 Hz per channel. The GUI also sends required control signals to the components on the data acquisition board. The data is stored together with the patient's information and acquisition parameters in an ASCII format file.

V. Results

Various experiments have been carried to test this device and verify its functionality. The results depict its capability of working in different situations as a portable and autonomic NIRS system. One of the experiments consisted in following up the changes in Hb and HbO_2 concentrations in the right Gastrocnemius muscle during contraction. The muscle was allowed to rest for 1 minute in the beginning for

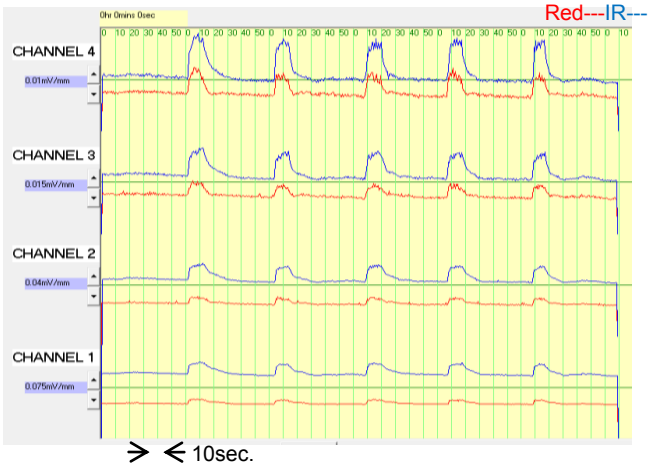

Figure.5. Raw data visualization for Gastrocnemius contraction.

a normal circulation. Then the subject was asked to stand in tip toe for 10 seconds to get the gastrocnemius muscle contracted. Then a rest period of 50 seconds was allowed. This was repeated 5 times and the raw data was acquired as shown in Fig.5. This data was then converted into Hb and HbO_2 concentrations as shown in Fig.6. It shows that the concentration of both chromophores decreases as the muscle is contracted, then after few seconds while keeping the contraction, the concentration of Hb starts to increase.

When the muscle relaxes, the concentrations of Hb and HbO_2 both come back to the original equilibrium level. Fig.6 shows that the change in concentrations of these two chromophores is more pronounced in channels acquiring information from deeper tissue layers also. These observations are in perfect agreement with normal physiological microcirculation phenomena

Another similar experiment dealt with the changes of Hb and HbO_2 concentrations in the right biceps muscle. The muscle was given 1 minute to relax and then it was

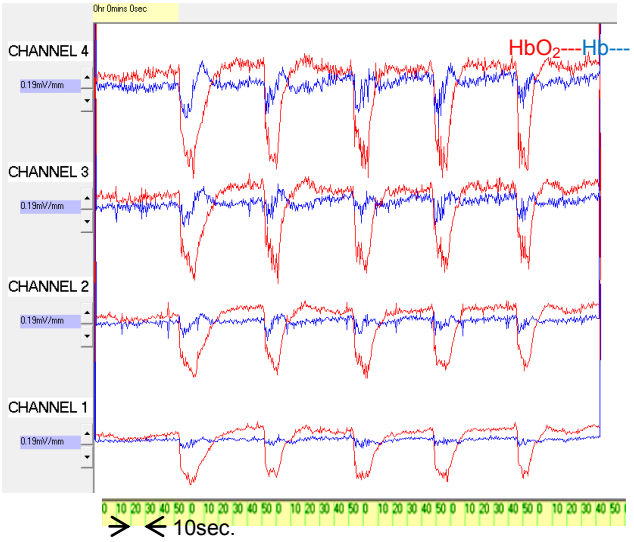

Figure.6. $HbO_2$and Hb visualization for Gastrocnemius contraction.

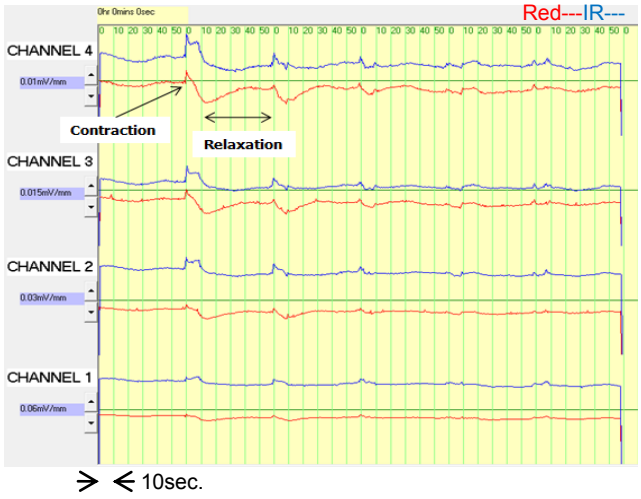

Figure.7. Raw data visualization for Biceps contraction.

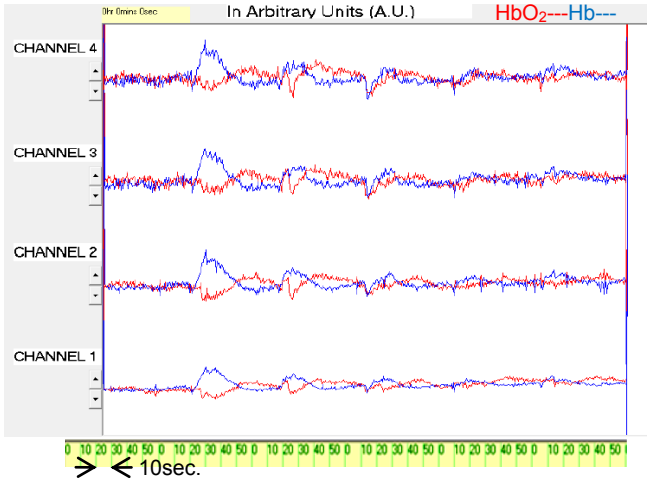

Figure.8. HbO_2 and Hb visualization for Biceps contraction.

contracted for 10 seconds. After that the muscle was given 50 seconds to recover, this protocol was repeated 5 times. In Fig.7 the changes are given as raw data and Fig.8 shows the determined changes in concentration of Hb and HbO_2.

VI. Conclusion

The design and development of a portable autonomic NIRS device has been described. The reliability and performance were evaluated under different experimental conditions. . The device could be used as a high resolution 8-channel system for depth resolving analysis which requires further implementation of advanced signal processing algorithms. Also, it could be turned into a comprehensive system by integrating other modalities like EEG and ECG thereby acquiring multiple physiological information. Due to their high resolution, portability, autonomy and user friendly nature, the developed system has a high potential to be accepted as a diagnostic tool.

References

[1] Villringer A. and Chance B. "Non –Invasive optical spectroscopy and imaging of human brain function".*TINS,*vol. 20(10), pp. 435-442, 1997.

[2] A V Patil, J Safaie, H AbrishamiMoghaddam, F Wallois and R Grebe. "Experi-mental investigation of NIRS spatial sensitivity", *Biomedical Optics Express*, Vol.2, No.6 (2011), 1478-1493.

[3] Rolfe P., Mondo G., Bottini F., Repetto D. and Ruggiero C. "Near Infra-Red Spectroscopy: a low cost device". In*Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society,* pp. 3147-3149, 2001.

[4] Strangman G., Boas D.A and Sutton J.P. "Non Invasive Neuroimaging Using Near-Infrared Light" in *Biological Psychiatry*, vol. 52, pp. 679-693, Oct 2002.

[5] F Wallois, A Patil, C. Héberlé, and R Grebe, "EEG-NIRS in epilepsy in children and neonates," *Neurophysiologie Clinique/Clinical Neurophysiology*, vol. 40, no. 5-6, pp. 281-292, Dec 2010.

[6] Gallagher A., Lassonde M., Bastien D., Vannasing P., Lesage F., Grova C., Bouthillier A., Carmant L., Lepore F., Beland R. and Nguyen D.K. "Non-invasive pre-surgical investigation of a 10 year-old epileptic boy using simultaneous EEG-NIRS" in *SEIZURE*, vol. 17, pp. 576-582, 2008.

[7] Kek K.J., Samizo M., Miyakawa T., Kudo N. And Yamamoto K."Imaging of Regional Differences of Muscle Oxygenation during Exercise Using Spatially Resolved NIRS" in *Proceedings of 27th Annual International Conference of the Engineering in Medicine and Biology Society*, pp. 2622-2625, Sept. 2005.

[8] Pogue B.W., Testorf M., McBride T., Osterberg U. and Paulsen K. "Instrumentation and design of a frequency-domain diffuse optical tomography imager for breast cancer detection " in *Optics Express*, vol. 1(13), pp. 391-403, Dec. 1997.

[9] Jobsis F.F. "Noninvasive Infrared Monitoring of Cerebral and Myocardial Oxygen Sufficiency and Circulatory parameters" in *Science*, vol. 198, pp. 1264-1267, Dec. 1977.

[10] Zhang Y., sun J.W., Wei G, Scopesi F., Serra G. and Rolfe P. "Design of a Portable Near Infra-Red Spectroscopy System for Tissue Oxygenation Measurement" in *3rd International Conference on Bioinformatics and Biomedical Engineering*, 2009, pp. 1-4, Jun. 2009.

[11] Chen W., Ayoola F., Oetomo S.B. and Feijs L. "Non-invasive Blood Oxygenation saturation Monitoring for Neonates Using Reflectance Pulse Oximeter" in *Proceedings of the Conference on Design, Automation and Test in Europe*, DATE 10, 2010.

[12] Mobley J. and Vo-Dinh T. "Optical Properties of Tissue" in *Biomedical Photonics Handbook*, Ed. Vo-Dinh T., USA: CRC Press LLC, 2003, pp. 10815-10837.

[13] Gratton E. and Fantini S. "Reflectance and transmittance spectroscopy" in *Lasers and current optical techniques in biology Comprehensive Series in Photochemistry and photobiology,* vol. 4, Palumbo G. and Pratesi R., Ed. Cambridge, U.K.: Royal Society of Chemistry, 2004, pp. 211-258.

[14] Derrick M.R., Stulik D. and Landry J.M. *Infrared Spectroscopy in Conservation Science*, USA: J. Paul Getty Trust, 1999, pp. 4-15.

[15] Bonanno A.S., Griffiths P.R. "Short-Wave near infrared spectra of organic liquids"in*Journal of Near Infrared Spectroscopy*, vol. 1, pp. 13-23, 1993.

[16] Benni P.B., Chen B., Amory D. and Li J.K.-J. "A novel near-infrared spectroscopy (NIRS) system for measuring regional oxygen saturation" in *Proceedings of the 1995 IEEE 21st Annual Northeast Bioengineering Conference*, pp. 105-107, 1995.