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Design and Development of Low-Cost, Handheld Near Infrared Spectroscopy (NIRS) Device for Neonatal Brain Functional Analysis with Phantom Studies

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Abstract

Near infrared spectroscopy (NIRS) is an emerging optical modality to analyze biological tissues non-invasively within the near infrared window (700-1000 nm). Since this technology uses non-ionizing light photon, it facilitates the physician for repeated diagnosis on specific regions of tissue continuously. A recent literature on clinical studies proves that some of the newborns especially premature babies have a high risk of potential brain injuries like intra ventricular haemorrhages and hypoxic-ischemia which can affect their mental growth. Therefore, there is a need for continuous monitoring of their brain function to identify and prevent any such abnormalities and it should not interfere with intensive care of the newborn as well. In this paper we depict the design, development and calibration of low-cost, handheld, dual wavelength, reflectance type continuous wave near infrared spectroscopy system for neonatal brain functional monitoring. The hardware component of the device includes the sensor patch with 2 LEDs of different wavelengths and 14 photo detectors together forming the dual octal geometry, ARDUINO AT MEGA 2560 with operating voltage of 5V and with clock speed of 16 MHz acts as the master controller, the pre-processing unit and the NI-DAQ card interfaced with PC. The software component includes LabVIEW for data analysis and an Arduino IDE which relies on java programming language and it is flexible to run on any platforms/operating system. The special features of the proposed device are its low cost, portability, low power consumption, less heat dissipation unlike laser systems, faster access, and controllability, provide optimal results and hence better accuracy.

1. Introduction

Near-infrared spectroscopy is one of the most promising modalities to emerge in recent years. This non-invasive optical technology is helping to advance a range of research and clinical applications from investigations of brain tissue in infants to functional imaging of breast cancer at very early stages, even before the cancer is visible with x-rays. Oxy-haemoglobin, deoxy-haemoglobin, water, lipid and cytochrome aa3 possess distinct absorption characteristics in the near infrared spectrum.

By monitoring absorption at different wavelengths, it is possible to determine the concentrations of oxy-haemoglobin, de-oxy haemoglobin, total haemoglobin, water and lipid. By determining its concentration in the particular regions of tissue specifically with cortical brain tissue of neonates, it is possible to identify the patho-physiological causes in the specific region of tissue for early diagnosis of any abnormalities. Thus, this above mentioned characteristic was the basic idea for emergence of NIRS instruments.

Moreover, it has an advantage of being an inexpensive device for functional neuro imaging comparable to electroencephalography (EEG), as opposed to fMRI, positron emission tomography (PET) and magneto encephalography. It does not require severely limiting subject motion. It can measure hemodynamic signals with a temporal resolution of 100 Hz or higher, significantly greater than fMRI or PET aiding in the resolution of the onset time of brain activation and in filtering physiological interference from the brain activation signals of interest.

Alper Bozkurt et al (2005) have presented a portable near infrared spectroscopy system for bedside monitoring of newborn brain. Nima Hemmatil et al (2012) have presented Multi-channel Near-Infrared Spectroscopy (NIRS) System for non-invasive Monitoring of Brain Activity. Former one was developed only with single LED and two detectors with a limited regional analysis. Later one has multi-channels but the working mechanism of controlling the sensor patch differs and it lacks in affordability. This research work has been developed with multiple sources and multiple detectors and single embedded kit controlling the entire sensor patch and the device with respect to the feedback obtained from the data acquisition card.

2. Theoretical background

A - NIRS INTERACTION WITH BIOLOGICAL TISSUES

Near–infrared optical imaging constitutes an evolution of the basic principles of NIR spectroscopy (NIRS), a method which was first demonstrated over 30 years ago and reported by Jöbsis in 1977. It has relatively high degree of transparency to biological tissue which enabled real-time non-invasive detection of tissue oxygen saturation. NIR optical window varies between 650 to 1000 nm in the absorption spectra.

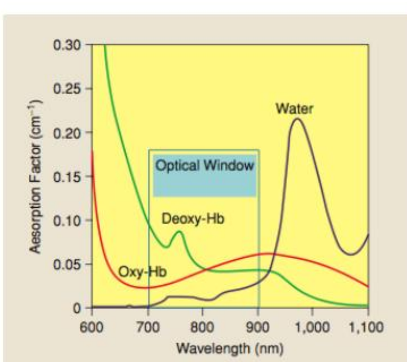

Figure 1. NIR absorption spectra

The relative transparency of human biological tissues to near infrared light is approximately from 650 nm to 1000 nm. Oxy-haemoglobin, deoxy-haemoglobin, water, lipid and cytochrome aa3 possess distinct absorption characteristics in the near infrared spectrum. By monitoring absorption at different wavelengths, it is possible to determine the concentrations of oxy-haemoglobin, de-oxy haemoglobin, total haemoglobin, water and lipid.

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B - BASIC PRINCIPLE BEHIND CONTINUOUS WAVE NIRS

When light in the near infrared (NIR) range of light is emitted through the scalp, injected photons follow various paths inside the head. Some of these photons are absorbed by different layers of the tissue such as skin, skull and brain. Others exit the head after following the banana pattern due to attenuation of light inside the tissue. Backscattered photons can be detected by means of appropriate photo detectors.

In continuous wave NIRS device, the change in the amount of blood chromophores in the tissue can be predicted by means of Modified Beer Lambert Law. When the NIR light source and detector are located on the scalp, the detector receives backscattered photons. Some of the injected photons are lost as a result of scattering and absorption due to different structures in the tissue. The attenuation of light between the source and detector can be formulated as follows:

$$I_{out} = I_{in} \cdot 10^{-OD_\lambda} \quad (1)$$

where Iin is incident light, I out is the detected light and OD_λ is the optical density for wavelength λ. Therefore, OD_λ can be defined as attenuation in intensity of light as a function of wavelength λ. This attenuation is the superposition of absorption (A_λ) and scattering (S_λ) of light with wave-length λ.

3. System hardware description

The developed hardware incorporates the NIRS sensor patch, controller unit, Multiplexers and PC fitted data acquisition unit. The operating voltage of the components of the sensor patch and the multiplexer ranges around 2.3V to 5V and the maximum output voltage given by the controller's digital pins were around 5V. Since each component was connected individually with the digital pins of the Arduino board, the above mentioned components can be provided with direct power supply and can attain direct controllability. Thus usage of driver boards can be avoided which adds the compactness to the system. The block diagram of the system is given below in the figure 3.

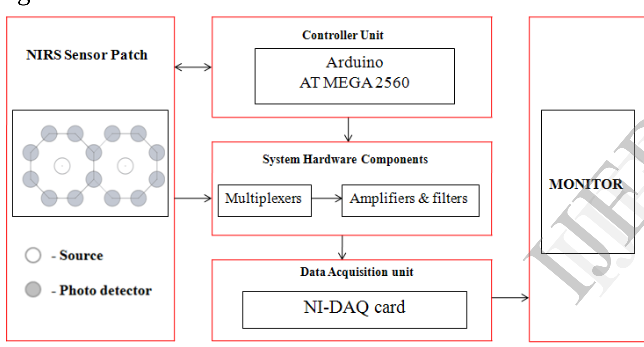

Figure 2. System block diagram

A. NIRS SENSOR PATCH DESIGN

The sensor patch comprises of two LED's of different wavelength (850nm & 940nm from Fairchild semiconductors). The 14 photo detectors (OPT101, Texas instruments) surround the LED forming the dual octagonal pattern. OPT101 has inbuilt operational amplifier. The distance between the source and detector is 15mm. The sensors were mounted on the printed circuit board by designing the circuit using orCAD software.

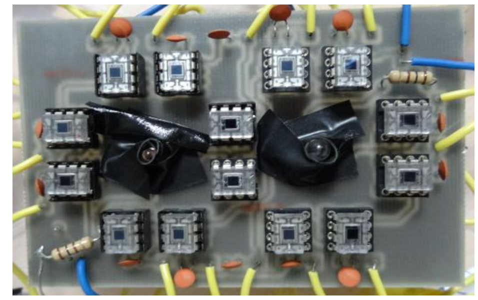

Figure 3. Sensors mounted on PCB

B. SYSTEM HARDWARE DESCRIPTION.

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

The Mega board is compatible with Linux and Windows. In this research work, the controller board manages almost entire system. Since it has maximum number of input /output pins, the LED's and photo detectors has been controlled and operated individually. The main benefit of using Arduino module was its low operating voltage (5V). It can even be operated using battery.

The controller unit makes the device to work systematically based on the feedback obtained from DAQ card. Each photo detector was connected to the Arduino module via multiplexers (HCC 4051B, ST microelectronics). Only the selected channels will give out the voltage of selected photo detectors at an instant of time. The selection of LED, a pair of photo detectors and their respective channels in multiplexers will be performed by the controller based on the task completion feedback obtained from the DAQ card.

4. Phantom

The instrument that has been designed and developed was tested with the solid phantom for calibration. The rectangular slab like phantom was prepared using paraffin wax. For analysis of absorption and scattering coefficient, the paraffin wax was heated to its melting temperature and color dye was mixed along with it and stirred well. Then the melted wax was poured inside the rectangular shaped prototype and allowed it to solidify at room temperature. Then the data was collected with the both the phantom to validate the results.

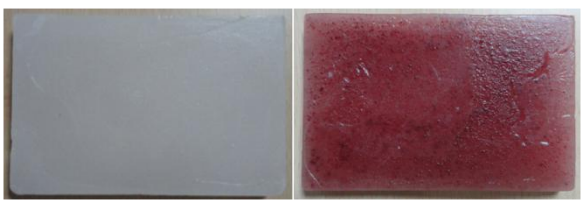

Figure 4. Solid phantoms

5. Results and discussion

Various initial experiments were performed before developing the actual hardware setup. The developed hardware was initially tested with the solid rectangular shaped phantom made up of paraffin wax

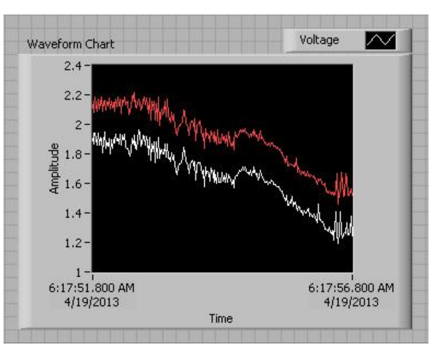

Figure 5. Response from the pair of photo detectors while illluminating 850nm LED.

The response of photodiodes with 850nm NIR emitter was obtained. The above results are the responses from the pair of photodiodes (5^{th} and 8^{th} photodiode). From the above results, we can infer that other photodiodes also showed similar. There are still certain errors in terms of responsitivity with some photodiodes .So, the device must be calibrated further and nullification of the system should be made using similar kind of phantom material. The variation in output intensity can be better noted with the pink phantom than the other two phantoms. The non-coincidence of two waveform in the above graph denotes the response of photo detectors are from two different regions.

6. Conclusion

The hardware for reflectance mode cwNIRS NIRS was designed. The inclusion of LED and photodiode in this work proves the low cost and portability of the system. The sensor geometry that has been designed provides uniqueness to the system when compared with the other devices in the market and from the current researches. The less expensive microcontroller which could control the entire sensor patches module and the multiplexers reduces the complexity of the system and provides user friendly environment. The main features of this system are design of sensor geometry, method of operating photodiodes at different instant of time, dual wavelength LED source, systematic working of the entire setup and data acquisition.

Further improvement may include the changes with NIR emitter, real time data acquisition, reconstruction of acquire data for optical topography to the application of neonatal brain functional analysis. This device can be developed to wireless module for transferring data which can add comfort to the neonates in neonatal intensive care unit (NICU) and also the system can be combined with EEG to develop the multimodal system.

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