# Functional Near-Infrared Spectroscopy (fNIRS) during Apnoea

Technical Note

TN 29082023

## PHYSICAL ACTIVITY | TASK DESCRIPTION

Heart is a vital organ, establishing itself as an adaptive pumping system, responsible for maintaining a constant blood flow along the different points of organism, through blood vessels.
With this triad (heart, blood vessels and blood) input nutrients can be delivered to cells and metabolic residues are extracted from them [1].
One of the most important elements to a living organism is oxygen, essential for cell to produce energy by aerobic respiration, which enters in the blood flow through the alveolar capillaries [2].
The delivery of oxygen is only possible due to the presence of erythrocytes in the blood, constituted by haemoglobin, a protein with a quaternary structure [3].
Each haemoglobin protein can carry up to four oxygen molecules (oxyhaemoglobin form) [4] and, after his delivering, carbon dioxide molecules are collected for being removed from the organism (deoxyhaemoglobin form).
Due to its importance, monitoring relative concentrations of these two haemoglobin conformations is extremely relevant, namely for knowing the oxygenation level of the blood.
To reach this purpose, electrophysiological acquisition sensors take advantage of the distinctive interaction of oxy- and deoxyhaemoglobin with red and infrared light [5], [6].
A functional near-infrared spectroscopy (fNIRS) sensor [7] uses a coupled set of two emitters (1 Red and 1 Infrared LED) and one photoreceptor in a reflectance mode.
This sensor is typically attached to the forehead, for monitoring the oxygenation levels at the pre-frontal cortex.
Sensor digital output is composed by two channels, that define the formed current on the photodiode due to the reflection of light from each emitter.
The fNIRS signal sample, referent to the present technical note, was acquired in apnoea conditions.

## SIGNAL CHARACTERISTICS

**Typical Frequency Band for $SpO_2$ estimate:**

- 0.50 to 3 Hz [Less Restrictive]
- 0.01 to 15 Hz [Recommended]

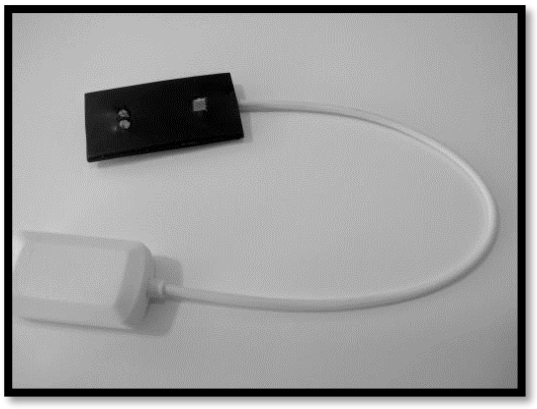

*Fig. 1. Sensor Overview*

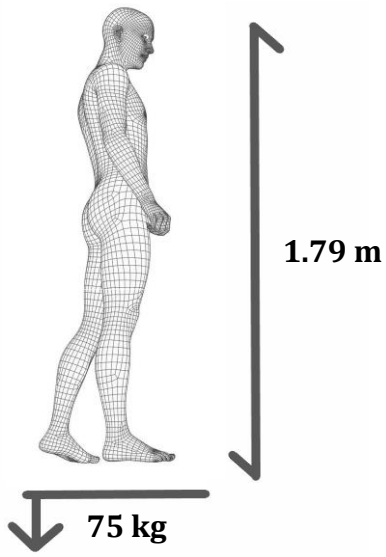


*Fig. 2. Anthropometric Measures*

PLUX – Wireless Biosignals,
S.A. Av. 5 de Outubro, n. 70 – 2.
1050-059 Lisbon, Portugal
www.pluxbiosignals.com

REV A

## SENSOR AND HARDWARE DESCRIPTION

The red (peak emission at 660 nm) and infrared light emitter (peak emission at 850 nm) are spaced by 2 mm from each other and the distance to the receptor is 23 mm [7].
Emitters and light receptor are positioned at the same plane (*Fig. 1*).

## SUBJECT DESCRIPTION

Healthy male subject with 25 years old and non-smoker (height: 1.79 m; weight: 75 kg - *Fig. 2*).

## PROTOCOL OF ACQUISITION

The subject was comfortably seated on a chair with the sensor placed on the forehead with the help of an elastic band.

Steps enumeration:

1. Placement of fNIRS sensor in the subject forehead (*Fig. 3*);
   The elastic band ensures the sensor fixation and isolation from external light sources.
2. Turn off external sources of noise, such as electric lights;
3. Start of the fNIRS acquisition;
4. During the first 15 seconds a normal breathing rhythm was maintained;
5. Between 15 and 50 seconds subject was requested to induce apnoea conditions by sustaining breath;
6. In the remaining 10 seconds restart of breathing takes place;
7. End of the acquisition after 1 minute;
8. Removal of the sensor from the subject forehead;
9. Storage of generated files in the desired folder (*Fig. 5*).

*Fig. 3. Sensor Placement (forehead)*

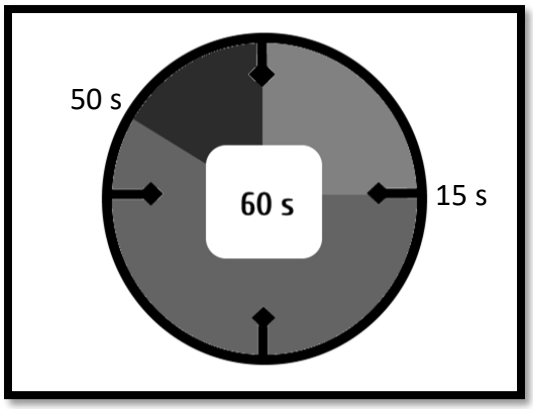


*Fig. 4. Time distribution of each protocol step*

*Fig. 5. Signal Storage Operation*

**QUICK INFORMATION**

The acquired data of fNIRS sensor is divided in two channels, one relative to the electric current formed due to the emitted red light and the other due to the emitted infrared light.
However, the researcher cannot make interpretations of oxygen saturation directly from the registered electric currents of each channel.
fNIRS and *SpO₂* sensors share the same functioning principles and because of that we can access oxygen saturation with the two methodologies.
It is needed to follow simple processing steps to convert the acquired data to *SpO₂* values, which will be explained briefly here.

A *SpO₂* value/sample was taken from each cardiac cycle, by following a determination procedure like the one described below.

The Red/Infrared Modulation Ratio (R) is essential for converting acquired current samples to *SpO₂* values, being inversely proportional to *SpO₂* [8].

$$R[i] = \frac{V_{pp}^{R}[i] \times V_{avg}^{IR}[i]}{V_{avg}^{R}[i] \times V_{pp}^{IR}[i]} \quad \textbf{(1)}$$

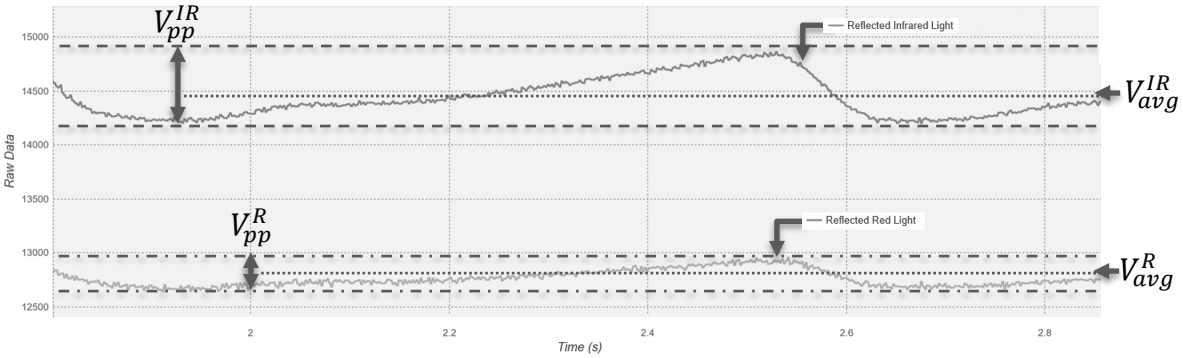


*Fig. 6. Segment of the signal sample, presenting the graphical correspondence of each term of equation (1)*

Each sensor has its own calibration curve that associates each R value to the correspondent *SpO₂* value.
For the present purposes we used a standard model (equation **(2)**) calibration curve [9], however, for greater precision measurements a more specific calibration curve should be delineated, representing the values of R (determined using the RAW fNIRS sensor data) versus $SpO_2$ values obtained through a calibrated oximeter.

$$\%\, SpO_2[i] = 110 - 25 \times R[i] \quad \textbf{(2)}$$

*SpO₂* evolution for the present signal sample is shown in *Fig. 7*.

It can be seen for the first 15 seconds the *SpO₂* level remains constant, when the subject was breathing normally.

At the second temporal segment (15 to 50 seconds in apnea), blood oxygenation starts decreasing gradually and suddenly an abrupt decrease happens.

In the final segment (restoring of normal breathing) the blood oxygenation level returns to the initial values.

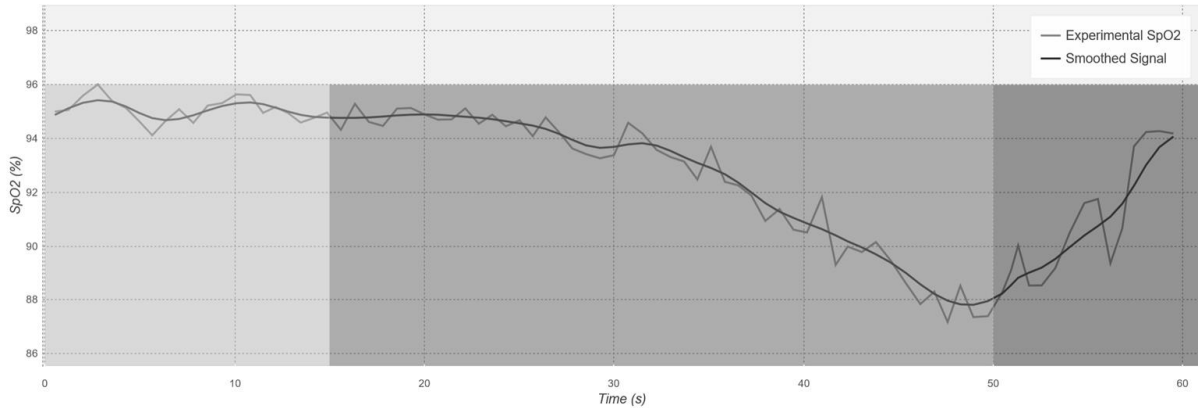


*Fig. 7. Evolution of the blood oxygenation level estimate for the signal sample under analysis*

**$SpO_2$ main values:**

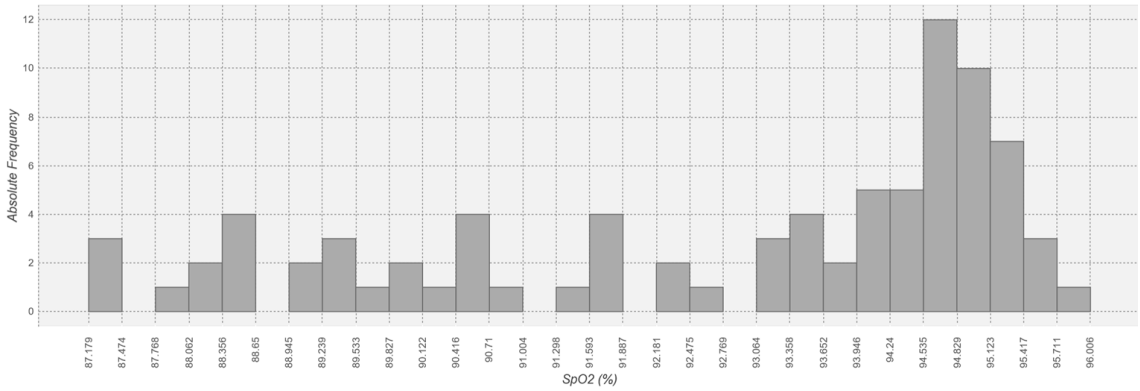


*Fig. 8. Distribution of $SpO_2$ samples*

$Average = 92.80\ \%$ $Standard\ Deviation$=2.54 %
$Maximum = 96.01\ \%$ $Minimum$=87.18 %

## NOISE EVALUATION PROCEDURE

*Signal to Noise Ratio* (SNR) is an important metric that classifies objectively the quality of the acquisition, and like the name suggests the relation between the intensity of the signal and the undesired noise in the acquired data ($acquired$), which is defined by:

$$SNR = \frac{V_{pp}^{signal}}{V_{pp}^{noise}} \quad \textbf{(3)}$$

being $V_{pp}^{signal}$ and $V_{pp}^{noise}$ the peak-to-peak amplitude of the $signal$ and $noise$ component, respectively.

In order to SNR be determined the following steps were followed:

**1)** Division of the acquisition in temporal segments/windows (each segment will be a cardiac cycle);

**2)** For each segment:
   a. Application of the acquired signal to a lowpass filter (for removal of high frequency noise);
   *A recommended frequency band for studying blood oxygen saturation is comprised between 0.01 and 15 Hz* [10]*. Like shown before, for converting the electric current values in meaningful $SpO_2$ samples, it is needed the preservation of the pulsatile nature of the acquired signal.*
   *With a more restrictive passband (0.5 to 3 Hz* [11]*) we can ensure this requisite and also remove more noise from the acquisition, which will bring us a better estimate of SNR.*
   *However, for the present acquisition the 15 Hz cut-off frequency seems to be the most appropriate, with higher frequency components containing small informational content (zoom of Fig. 9)*
   *The applied digital filter was a 6th Butterworth with a cut-off frequency of 15 Hz in order to ensure that the 50 Hz peak was attenuated (at 50 Hz the gain is -40 dB), like shown in Fig. 9 and Fig. 10.*

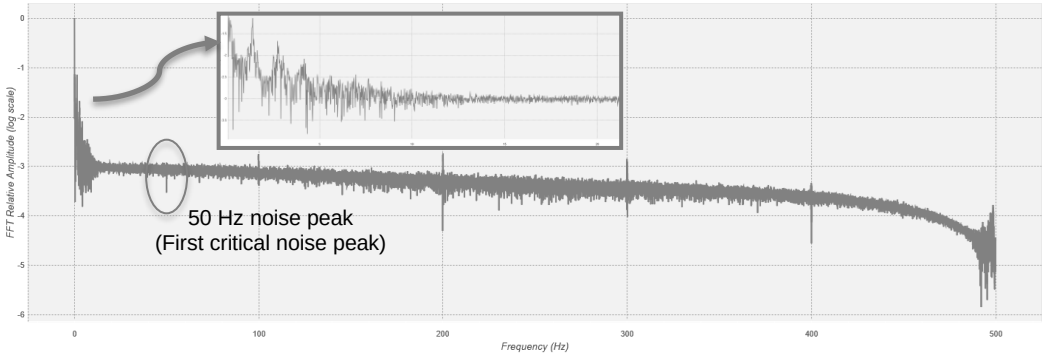


*Fig. 9. Signal Power Spectrum and identification of the 50 Hz noise peak inside the ellipse*

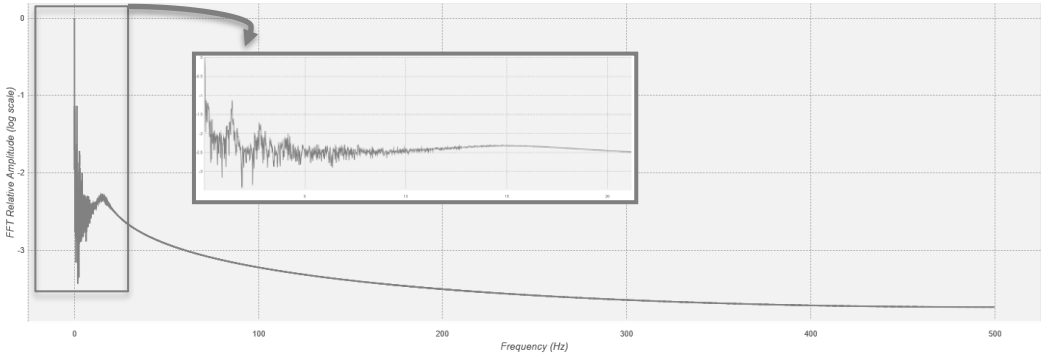


*Fig. 10. Filtered Signal Power Spectrum and highlighting of the informational band*

b. Determination of $V_{pp}^{signal}$ from the smoothed/filtered blood pulse (*Fig. 11*);

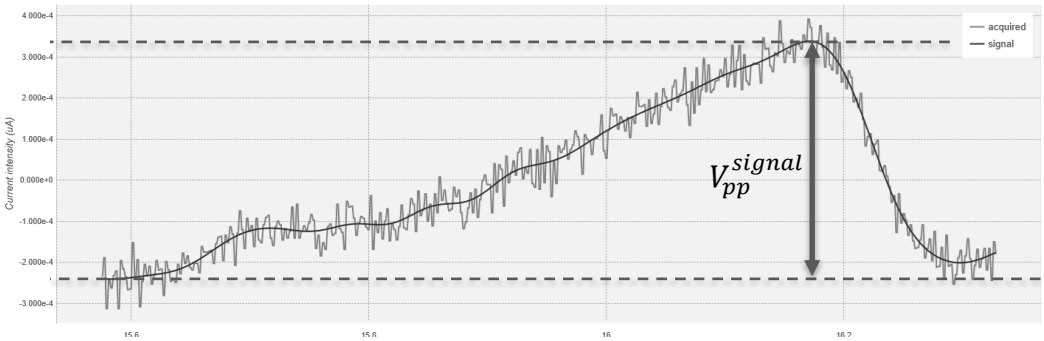


*Fig. 11. Smoothed data*

c. Isolation of the noise component by subtracting the filtered data (signal component) from the acquired signal (*Fig. 12*);

d. Determination of $V_{pp}^{noise}$;

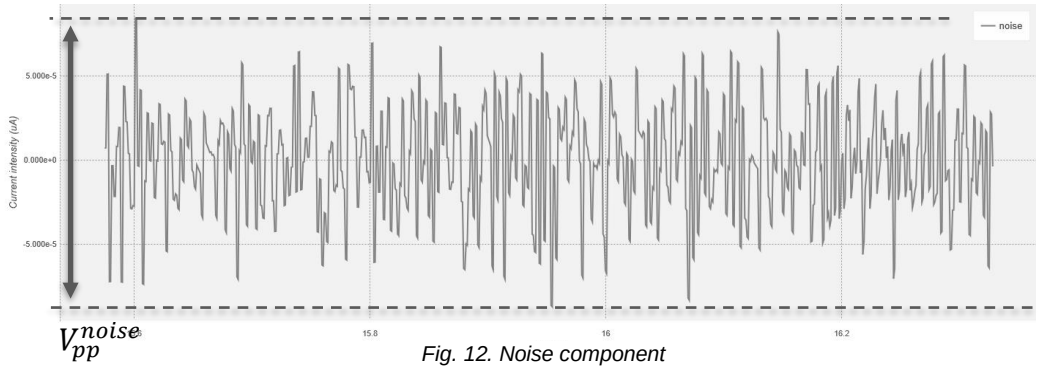


*Fig. 12. Noise component*

e. Estimation of SNR for the present segment.

**3)** Average of the SNR values and the respective standard deviation.

$$SNR_{avg} = 4.41 \qquad SNR_{std} = 1.91$$

$$SNR_{avg}^{dB} = 12.89 \pm \frac{3.12\ dB}{4.93\ dB}$$

## REFERENCES

[1] J. E. Hall and A. C. Guyton, “Overview of the Circulation: Biophysics of Pressure, Flow, and Resistance,” in *Guyton and Hall: Textbook of Medical Physiology*, 12th ed., Philadelphia, PA: Saunders Elsevier, 2011, pp. 157–166.
[2] R. Bear, D. Rintoul, B. Snyder, M. Smith-Caldas, C. Herren, and E. Horne, “Overview of Cellular Respiration,” in *Principles of Biology*, Kansas: Open Access Textbooks, 2016, pp. 351–371.
[3] J. M. Berg, J. L. Tymoczko, and L. Stryer, “Hemoglobin Transports Oxygen Efficiently by Binding Oxygen Cooperatively,” in *Biochemistry*, New York: W H Freeman, 2002.
[4] L. Costanzo, “Respiratory Physiology,” in *Physiology*, 4th ed., Philadelphia, PA: Saunders Elsevier, 2010, pp. 183–234.
[5] L. A. Tuscan, J. D. Herbert, E. M. Forman, A. S. Juarascio, M. Izzetoglu, and M. Schultheis, “Exploring frontal asymmetry using functional near-infrared spectroscopy: A preliminary study of the effects of social anxiety during interaction and performance tasks,” *Brain Imaging Behav.*, vol. 7, no. 2, pp. 140–153, 2013.
[6] M. Ferrari and V. Quaresima, “A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application,” *Neuroimage*, vol. 63, no. 2, pp. 921–935, 2012.
[7] Plux Wireless Biosignals, “fNIRS Sensor Data Sheet.” 2017.
[8] E. D. Chan, M. M. Chan, and M. M. Chan, “Pulse oximetry : Understanding its basic principles facilitates appreciation of its limitations,” *Respir. Med.*, vol. 107, no. 6, pp. 789–799, 2013.
[9] Texas Instruments, “How to Design Peripheral Oxygen Saturation (SpO2) and Optical Heart Rate Monitoring (OHRM) Systems Using the AFE4403,” Dallas, Texas, 2015.
[10] N. Stuban and M. Niwayama, “Optimal filter bandwidth for pulse oximetry,” *Rev. Sci. Instrum.*, vol. 83, no. 10, pp. 1–6, 2012.
[11] Y.T. Li, “Pulse Oximetry,” *SEPS Undergrad. Res. J.*, vol. 2, no. 6, pp. 11–15, 2007.