Blood Oxygen Saturation (SpO_2) during Apnoea

Technical Note

TN 12072018

PHYSICAL ACTIVITY | TASK DESCRIPTION

Energy is not tangible in the real sense of the word but is present in all physical phenomenon's and scales, including, of course, the microscopic/cellular level [1].

Each human cell needs energy to ensure his vital functions, in this case in a chemical form through dephosphorylation of ATP molecule [2].

In order to ATP be produced in great quantities, the cell executes a sequence of metabolic steps, which compose the aerobic respiration mechanism.

Oxygen takes an important part in this mechanism, so, a constant and intense supply is needed, after this molecule enters in the blood flow through the alveolar capillaries [3].

The delivery of oxygen is only possible due to the presence of erythrocytes in the blood, constituted by haemoglobin, a protein that can transport until four oxygen molecules (oxyhaemoglobin) and by changing conformation also had the capability of taking carbon dioxide from cells (deoxyhaemoglobin) [4].

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].

SpO_2 sensor [6] is composed by a set of two emitters (1 Red and 1 Infrared LED) and one photoreceptor in a reflectance mode.

This sensor should be placed at a high vascularized zone, for example at body extremities such as fingers [5].

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 signal sample, referent to the present technical note, was acquired in apnoea conditions.

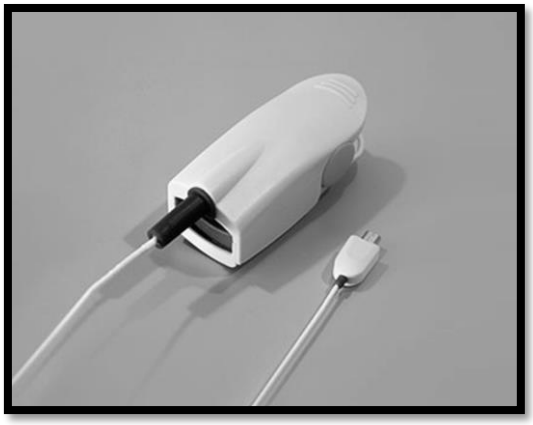

Fig. 1. Sensor Overview

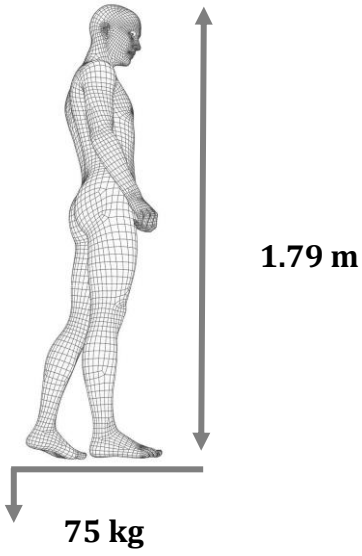

Fig. 2. Anthropometric Measures

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REV A

SENSOR AND HARDWARE DESCRIPTION

The red (peak emission at 660 nm) and infrared light emitter (peak emission at 950 nm) are activated in an intermittent mode (duty cycle of 25 %).
Additionally the intensity of light emitted can be manually adjusted in the *OpenSignals* interface [6].
For the present acquisition SpO_2 sensor was incorporated inside a finger clip, to monitorization of blood oxygenation be made at the finger (*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

During the acquisition the subject was comfortably seated on a chair and is requested to stop breathing with the aim that blood oxygenation variations be induced.

Steps enumeration:

1. Placement of SpO_2 sensor in the subject forefinger (*Fig. 3*);
2. Turn off external sources of noise, such as electric lights;
3. Start of the SpO_2 acquisition;
4. Maintenance of normal breathing rhythm for 15 seconds;
5. At 15 seconds time instant subject induces apnoea conditions by sustaining breath, during 35 seconds;
6. In the remaining time (40 seconds) restart of breathing takes place;
7. End of the acquisition after 1 minute and 30 seconds;
8. Removal of the sensor from the subject forefinger;
9. Storage of generated files in the desired folder (*Fig. 5*).

Fig. 3. Sensor Placement (forefinger)

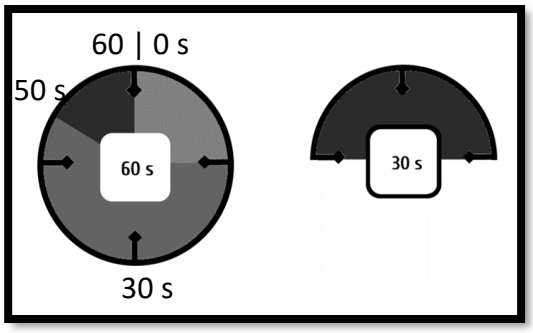

Fig. 4. Time distribution of each protocol step

Fig. 5. Signal Storage Operation

QUICK INFORMATION

Taking into account the basic principles inherent to *SpO₂* acquisition, two emitters were used, and the receptor collects information about each one in an intermittent way.
So, the acquisition file 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.
This electric current data needs to be converted to blood oxygenation level estimates. To achieve this final format the following processing steps should be followed.

Considering a 1 seconds window (referred as window i), the Red/Infrared Modulation Ratio (R) is essential for converting acquired current samples to *SpO₂* values, being inversely proportional to *SpO₂* [5].

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

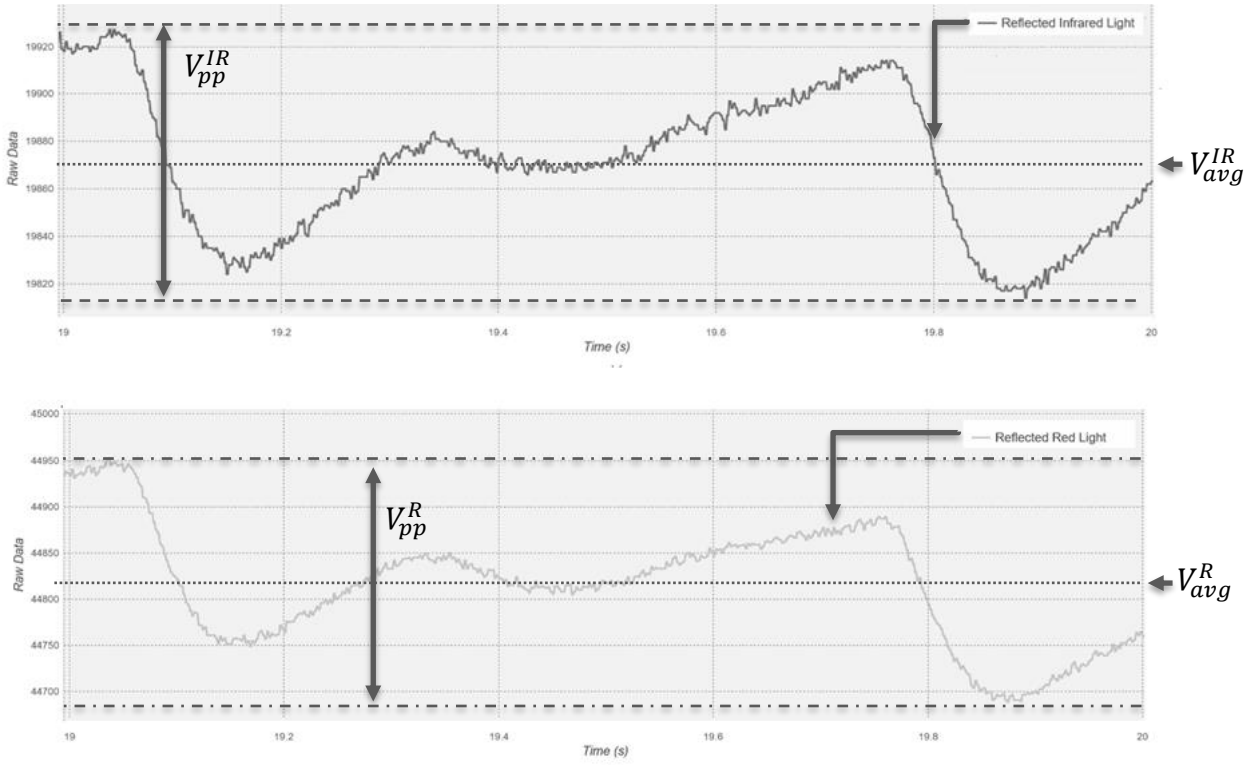

Fig. 6. Segment of the signal sample, presenting the graphical correspondence of each term of equation (1)

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 [7] with a correction step, that ensures the approaching of values to our sensor specificities

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

Making an assumption that at the start of acquisition *SpO₂* is in a normal level (95 %), the final value is found by:

$$\%\, SpO_2^{rev}[i] = \frac{\%\, SpO_2[i] \times 95}{\max(\%\, SpO_2)} \quad \textbf{(3)}$$

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

It can be seen for the first 15 seconds the SpO_2 level remains at a high level with an increase at the final stage due to the suspension of breathing and inhaled air retention.

Between 15 and 50 seconds (in apnoea) there were an initial period where SpO_2 did not change considerably. Near 40 seconds an abrupt drop of SpO_2 occurs.

During the reestablishment of breathing (50 to 90 seconds) exists a great oscillation in SpO_2 estimate when rebreathe, followed by a gradual increase of SpO_2 until the starting values were reached.

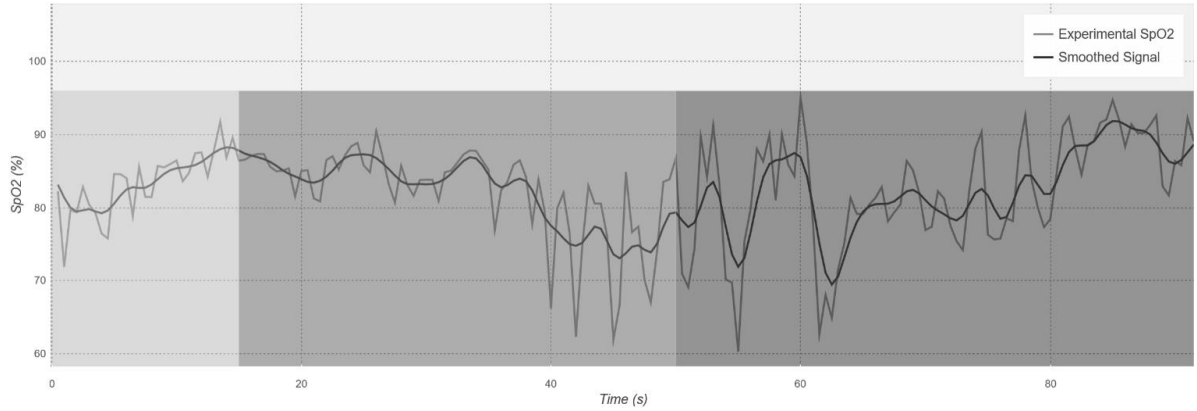

Fig. 7. Evolution of the blood oxygenation level estimate for the signal sample under analysis

***Note:** The previous SpO_2 values are estimates that require further validation in order to the normalization reference value (in this case it was assumed that the maximum value corresponds to a SpO_2 value of 95 %) will be in accordance to Plux's sensor specifications.*

SpO_2 main values:

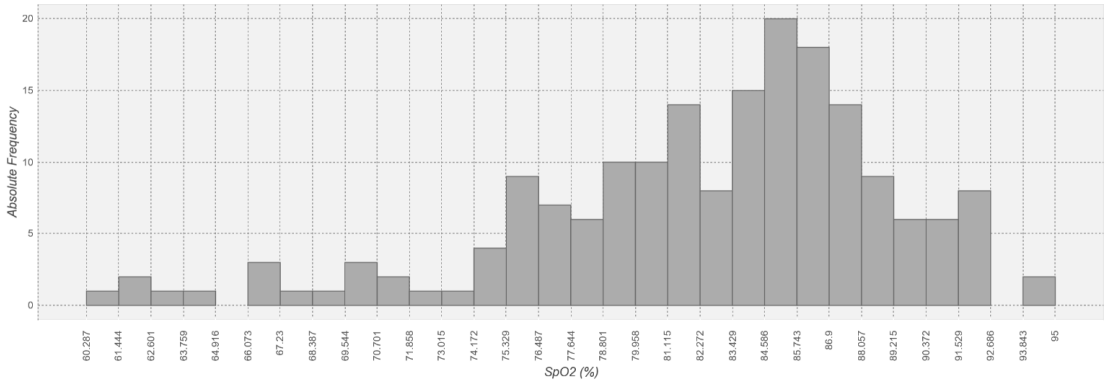

Fig. 8. Distribution of SpO_2 samples

$Average = 82.49\ \%$ $Standard\ Deviation = 6.66\ \%$
$Maximum = 95.00\ \%$ $Minimum = 60.29\ \%$

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:

$$SNR = \frac{V_{pp}^{signal}}{V_{pp}^{noise}} \quad \textbf{(4)}$$

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 [8]*. 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 [9]*) 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.

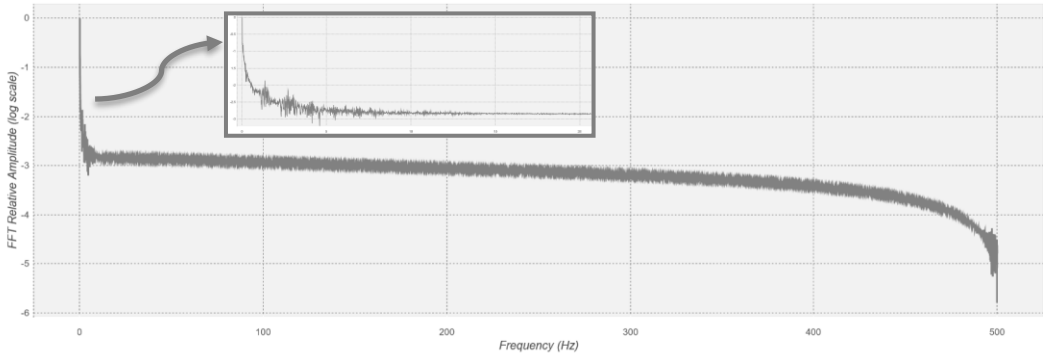

Fig. 9. Signal Power Spectrum with the zoom of the informational band

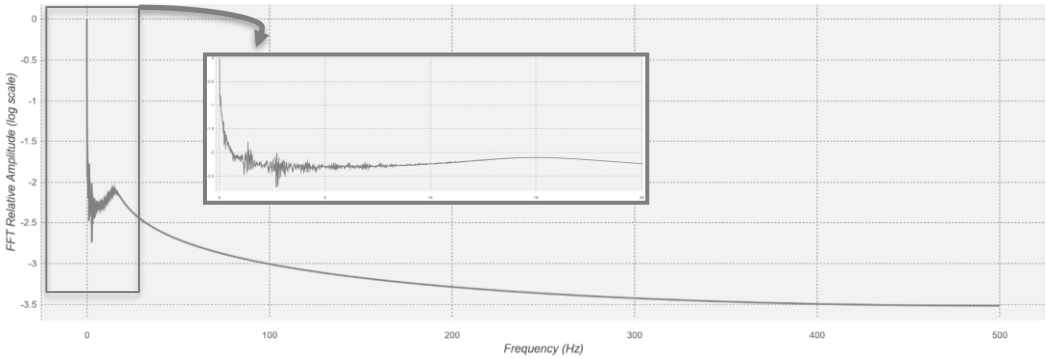

Fig. 10. Filtered Signal Power Spectrum and highlighting of the informational band

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

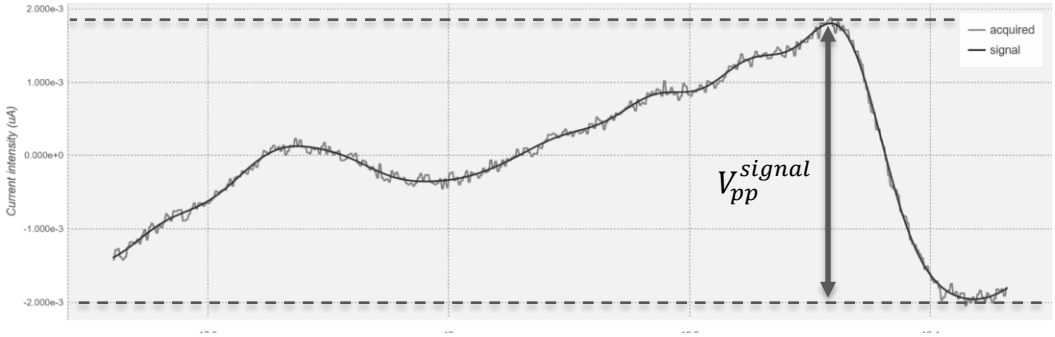

Fig. 11. Smoothed data

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};

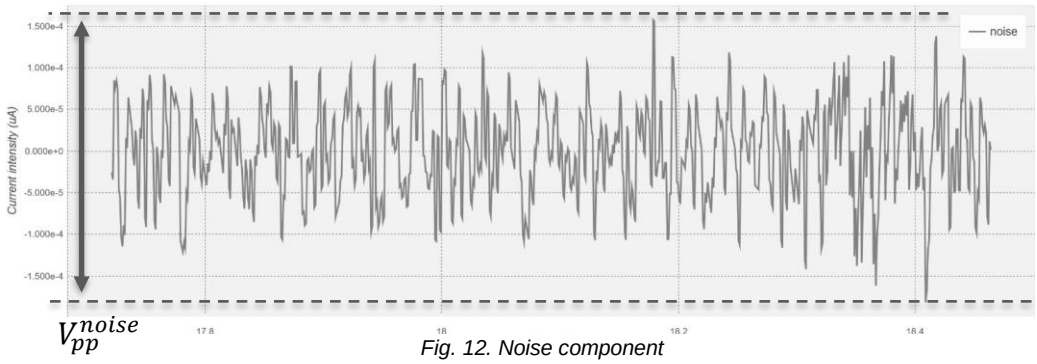

Fig. 12. Noise component

e. Estimation of SNR for the present segment.

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

$$SNR_{avg} = 10.83 \qquad SNR_{std} = 4.70$$

$$SNR_{avg}^{dB} = 20.69 \pm \frac{3.13\ dB}{4.94\ dB}$$

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