

Respiration Processing Module

for Biosignals Studio

Datasheet



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Biosignals Studio

This software module is intended solely for life sciences research and educational purposes. It is not a medical device and is not intended for diagnosis, treatment, or any form of medical use.

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General Information

The **Respiration Processing Module** for Biosignals Studio turns a raw inductive respiration signal into breath-by-breath and segment-level respiration parameters, with automatic detection of apnea phases.

This datasheet describes the technical implementation of the module: supported sensors, settings, pre-processing steps and the formulas used to compute every extracted parameter. For instructions on using the module in Biosignals Studio, visit support.pluxbiosignals.com.

The module processes the selected signal segment in the following order:

1. Band-pass filtering of the raw signal
2. Optional min-max normalization
3. Peak (end of inhalation) and valley (end of exhalation) detection
4. Breathing cycle segmentation and removal of incomplete cycles
5. Apnea detection
6. Extraction of the Respiration Rate (RR) and Breath-to-Breath Interval (BBI) series
7. Computation of temporal statistics and per-cycle parameters

All extracted parameters are timing-based: they are derived from the timestamps of detected peaks and valleys, not from signal amplitude.

Datasheet

Overview

Table 1: General Information

Attribute	Information
Product Name	Respiration Processing Module
Product Type	Signal Processing Module (software)
Software	Biosignals Studio
Description	Processing module for inductive respiration signals, providing pre-processing, breathing cycle detection, apnea detection and extraction of respiration parameters.
Features	- Band-pass filtering and optional normalization - Automatic peak and valley detection - Configurable breathing cycle start (valley or peak) - Automatic detection of post-inhalation and post-exhalation apnea - Respiration rate and breath-to-breath interval statistics - Per-cycle timing parameters (inhalation, exhalation, I:E ratio)
Use Case Applications	- Cardiorespiratory coupling - Sleep and apnea research - Psychophysiology and stress monitoring - Relaxation and breathing studies - Sports sciences (breathing control, recovery)
Excluded Applications	This module is not a medical device and must not be used for clinical diagnosis or treatment.
Compatible Sensors	Inductive respiration (RIP) sensors (see Supported Sensors)
Incompatible Sensors	Piezo-electric respiration (PZT) sensors and BITalino systems

Supported Sensors

The module supports inductive respiration sensors based on Respiratory Inductance Plethysmography (RIP), which measure the cross-sectional changes of the thorax or abdomen during breathing.

Table 2: Supported sensors and systems

Sensor	System	Supported
Respiration (RIP) Smart Sensor	Biosignals PRO	Yes
Respiration (RIP)	Biosignalsplux & Biosignals PRO	Yes
respiBAN BLE	Standalone wearable	Yes
Piezo-electric Respiration (PZT)	biosignalsplux	No
Respiration sensors	BITalino	No

Settings

Six user settings control normalization, cycle detection and apnea detection. All other processing parameters are fixed.

Table 3: User settings

Setting	Symbol	Default	Unit	Effect
Minimum apnea duration	$D_{\min}$	5	s	Shortest low-slope segment accepted as an apnea phase
Slope analysis window	W	2	s	Length of the moving-average window for the local mean slope
Slope acceptance ratio	α	0.4	-	Fraction of the local mean slope below which the signal is considered flat
Refractory period	T_{ref}	0.8	s	Minimum time between two consecutive peaks (or valleys); limits the maximum detectable rate to $60 / T_{\text{ref}} = 75$ breaths/min
Cycle start	-	Valley	-	Valley: cycles run valley to valley (inhalation first). Peak: cycles run peak to peak (exhalation first)
Signal normalization	-	Disabled	-	Applies min-max normalization to the filtered signal

Table 4: Fixed processing parameters

Parameter	Value
Band-pass filter	Butterworth, 4th order
Lower cut-off frequency	0.05 Hz
Upper cut-off frequency	1 Hz
Minimum peak prominence	0.05
Minimum peak width	0.2 s

Pre-Processing

The raw signal $x[n]$, sampled at f_s , is filtered, optionally normalized, and segmented into complete breathing cycles before any parameter is computed.

Band-Pass Filtering

A 4th order Butterworth band-pass filter (0.05 to 1 Hz) removes slow baseline drift and high-frequency noise while preserving the breathing waveform. The passband covers breathing rates from 3 to 60 breaths/min, in line with the respiratory frequency bands used in respiration and respiratory rate estimation literature [2]. The same band-pass configuration has been applied in respiration studies using PLUX sensors [10], [11].

Signal Normalization (Optional)

When enabled, the filtered signal is scaled to the range [0, 1] with min-max normalization. This reduces the influence of sensor placement on signal offset and amplitude when comparing participants or recordings [PLUX]. Normalizing respiration signals before comparing participants is common practice in multimodal physiological studies [11], [12].

$$x_{norm}[n] = \frac{x[n] - \min(x)}{\max(x) - \min(x)}$$



Signal appears flat after normalization:

The raw RIP signal uses a 24-bit range that varies strongly between participants and sensor placements. When displayed next to the raw signal, the normalized signal can therefore appear flat at zero. Disable normalization if this is not intended.

Peak and Valley Detection

Peaks $P = \{t_{p,1}, \dots, t_{p,K}\}$ mark the transition from inhalation to exhalation. Valleys $V = \{t_{v,1}, \dots, t_{v,K}\}$ mark the transition from exhalation to inhalation.

Peaks are detected with a local-maximum search on the pre-processed signal, and valleys with the same search on the inverted signal $-x[n]$. A candidate is accepted only if it meets all three conditions:

Table 5: Peak and valley acceptance criteria

Condition	Criterion
Minimum distance to the previous peak (or valley)	≥ 0.8 s (default)
Minimum prominence	≥ 0.05
Minimum width	≥ 0.2 s

Breathing Cycle Definition

A breathing cycle k is bounded by two consecutive detections of the cycle start type [3]:

- **Valley (default):** cycle k starts at valley $t_{v,k}$, contains peak $t_{p,k}$ and ends at valley $t_{v,k+1}$ (inhalation, then exhalation).
- **Peak:** cycle k starts at peak $t_{p,k}$, contains valley $t_{v,k}$ and ends at peak $t_{p,k+1}$ (exhalation, then inhalation).

Cycle Correction

Only complete cycles are analyzed. Peaks before the first valley and after the last valley (Valley mode), or valleys before the first peak and after the last peak (Peak mode), are discarded. This yields K complete cycles in the analyzed segment.

Apnea Detection

Apnea phases are segments where the respiration signal shows little to no slope for at least the minimum apnea duration. Detection uses an adaptive slope threshold so that slow or shallow breathing is not mistaken for apnea:

1. The absolute first derivative (slope) of the pre-processed signal is computed.
2. The slope is smoothed with a moving average of length W to obtain the local mean slope.
3. Samples whose slope is below α times the local mean slope are flagged as low-slope. The ratio α narrows the flagged segment so it does not overlap with correctly detected peaks or valleys.
4. Contiguous low-slope segments lasting at least $D_{\min}$ are accepted as apnea phases.

The method detects both post-inhalation apnea (breath held after inhaling) and post-exhalation apnea (breath held after exhaling). Clinical sleep scoring defines an apnea as a cessation of airflow lasting at least 10 s [4]; set $D_{\min}$ accordingly when the module is used for sleep research.

Extracted Parameters

All parameters are computed from the timestamps of the K complete breathing cycles. In the formulas, $t_{s,k}$ and $t_{e,k}$ are the start and end of cycle k, and $t_{x,k}$ is its transition point (the peak in Valley mode, the valley in Peak mode). Standard deviations use the sample estimator (N – 1).

Core Series

The Respiration Rate (RR) series and the Breath-to-Breath Interval (BBI) series are the inputs for all temporal statistics [3], [8]:

$$BBI_k = t_{s,k+1} - t_{s,k}, \quad RR_k = \frac{60}{BBI_k}$$

Respiration Rate Parameters

Table 6: Respiration rate parameters

Parameter	Unit	Reference
Minimum Respiration Rate	breaths/min	[8]
Maximum Respiration Rate	breaths/min	[8]
Relative Respiratory Rate Variability	%	[5]

Minimum and Maximum Respiration Rate – lowest and highest value of the RR series across all K cycles:

$$RR_{min} = \min_k RR_k, \quad RR_{max} = \max_k RR_k$$

Relative Respiratory Rate Variability – standard deviation of the RR series divided by its mean, expressed as a percentage (coefficient of variation):

$$RRV_{rel} = \frac{SD(RR)}{\overline{RR}} \times 100 \%$$

Standard deviation of the respiration rate – used in the Relative Respiratory Rate Variability above:

$$SD(RR) = \sqrt{\frac{1}{K-1} \sum_{k=1}^K (RR_k - \overline{RR})^2}$$

Breath-to-Breath Interval (BBI) Parameters

SD BBI, RMSSD and SDSD apply the time-domain Heart Rate Variability (HRV) metrics [6], [7] to the BBI series. This adaptation is a PLUX extension; breath-to-breath variability itself is an established measure of the respiratory pattern [5], [9].

Table 7: Breath-to-Breath Interval parameters

Parameter	Unit	Reference
Minimum BBI	s	[PLUX]
Maximum BBI	s	[PLUX]
Mean BBI	s	[5]
SD BBI	s	[PLUX], adapted from SDNN [6]
RMSSD	s	[PLUX], adapted from RMSSD [6], [7]
SDSD	s	[PLUX], adapted from SDSD [6]

Minimum and Maximum BBI – shortest and longest breath-to-breath interval:

$$BBI_{min} = \min_k BBI_k, \quad BBI_{max} = \max_k BBI_k$$

Mean BBI – average of all breath-to-breath intervals:

$$\overline{BBI} = \frac{1}{K} \sum_{k=1}^K BBI_k$$

SD BBI – standard deviation of all breath-to-breath intervals (overall variability):

$$SD \text{ BBI} = \sqrt{\frac{1}{K-1} \sum_{k=1}^K (BBI_k - \overline{BBI})^2}$$

Successive differences – change in BBI from one breath to the next, used to compute RMSSD and SDSD:

$$\Delta BBI_k = BBI_{k+1} - BBI_k, \quad k = 1, \dots, K-1$$

RMSSD – root mean square of the successive differences (short-term variability):

$$\text{RMSSD} = \sqrt{\frac{1}{K-1} \sum_{k=1}^{K-1} \Delta \text{BBI}_k^2}$$

SDSD – standard deviation of the successive differences (short-term variability):

$$\text{SDSD} = \sqrt{\frac{1}{K-2} \sum_{k=1}^{K-1} (\Delta \text{BBI}_k - \overline{\Delta \text{BBI}})^2}$$

SD BBI reflects overall variability across the segment. RMSSD and SDSD both reflect short-term, breath-to-breath variability; for long series with a mean successive difference close to zero, their values converge [7].

Breathing Cycle Parameters

The following parameters are computed for every cycle k [3], [8].

Table 8: Breathing cycle parameters

Parameter	Unit	Valley mode	Peak mode
Cycle Start	s:ms	$t_{s,k} = t_{v,k}$	$t_{s,k} = t_{p,k}$
Cycle End	s:ms	$t_{e,k} = t_{v,k+1}$	$t_{e,k} = t_{p,k+1}$
Transition Point	s	$t_{x,k} = t_{p,k}$	$t_{x,k} = t_{v,k}$
Cycle Duration (T_{tot})	s	$t_{e,k} - t_{s,k}$	$t_{e,k} - t_{s,k}$
Respiration Rate	breaths/min	$60 / T_{\text{tot},k}$	$60 / T_{\text{tot},k}$
Inhalation Duration (T_i)	s	$t_{x,k} - t_{s,k}$	$t_{e,k} - t_{x,k}$
Exhalation Duration (T_e)	s	$t_{e,k} - t_{x,k}$	$t_{x,k} - t_{s,k}$
Inhale-to-Exhale Ratio (I:E)	-	$T_{i,k} / T_{e,k}$	$T_{i,k} / T_{e,k}$

For all non-timestamp parameters p , the module also reports the mean and standard deviation across all K cycles [PLUX]:

$$\bar{p} = \frac{1}{K} \sum_{k=1}^K p_k, \quad \text{SD}(p) = \sqrt{\frac{1}{K-1} \sum_{k=1}^K (p_k - \bar{p})^2}$$

Timestamp parameters (Cycle Start, Cycle End, Transition Point) are excluded from the mean and standard deviation.

For any cycle, $T_i + T_e = T_{\text{tot}}$. In quiet breathing, healthy adults typically show T_i shorter than T_e , giving an I:E ratio below 1 [3].

Bibliography

[PLUX] Methods and parameters defined by PLUX for this module, based on the internal requirements specification for the Respiration Processing Module.

This covers min-max normalization, cycle correction, the apnea detection algorithm, Minimum and Maximum BBI, the per-cycle mean and standard deviation, and the adaptation of HRV time-domain metrics (SD BBI, RMSSD, SDSD) to the BBI series.

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Regulatory & Legal

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Document Version & Revision History

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1.0	14/10/2026	First version



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