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(54) **Titre : DISPOSITIF DE PLETHYSMOGRAPHIE PAR INDUCTANCE RESPIRATOIRE FAIBLE PUISSANCE, VETEMENTS INTELLIGENTS OU ARTICLES A PORTER EQUIPES DUDIT DISPOSITIF ET UNE METHODE D'ANALYSE DE L'ACTIVITE RESPIRATOIRE**

(54) **Title: LOW-POWER RESPIRATORY INDUCTANCE PLETHYSMOGRAPHY DEVICE, INTELLIGENT GARMENTS OR WEARABLE ITEMS EQUIPPED THEREWITH AND A METHOD FOR RESPIRATORY ACTIVITY ANALYSIS**

(57) **Abrégé/Abstract:**
The present invention relates to a low power Respiratory Inductance Plethysmography (RIP) sensor inside a wearable system, an intelligent wearable garment equipped therewith and a method for respiratory activity analysis. The wearable garment receives the signal conditioning for the electronic analog front end. The RIP circuit uses a Colpitts oscillator configuration with an oscillation in the frequency band 1MHz to 15MHz. The wearable device connects through a low impedance connector to keep RIP loop resistivity as low as possible.

ABSTRACT

The present invention relates to a low power Respiratory Inductance Plethysmography (RIP) sensor inside a wearable system, an intelligent wearable garment equipped therewith and a method for respiratory activity analysis. The wearable garment receives the signal conditioning for the electronic analog front end. The RIP circuit uses a Colpitts oscillator configuration with an oscillation in the frequency band 1MHz to 15MHz. The wearable device connects through a low impedance connector to keep RIP loop resistivity as low as possible.

LOW-POWER RESPIRATORY INDUCTANCE PLETHYSMOGRAPHY DEVICE, INTELLIGENT GARMENTS OR WEARABLE ITEMS EQUIPPED THEREWITH AND A METHOD FOR RESPIRATORY ACTIVITY ANALYSIS

[0001] The present describes a Respiratory Inductance Plethysmography (RIP) sensor using an optimal Colpitts oscillator configuration for an efficient human body measurement, a garment or other wearable item equipped therewith and a method for respiratory activity analysis.

BACKGROUND

[0002] Physiological sensors have long been known and widely used for medical and health related applications. Various physiological sensors embedded in textile or garments, sometimes called portable or wearable sensors, have been described before in publications and patents (Portable Blood Pressure, U.S. Patent number: 4,889,132; Portable device for sensing cardiac function, U.S. Patent number: 4,928,690). The term "wearable sensors" is now commonly used to describe a variety of body-worn sensors to monitor activity, environmental data, body signals, biometrics, health related signals, and other types of data.

[0003] Textile-based Respiratory Inductive Plethysmography (RIP) sensors have been described in patents such as (Method and apparatus for monitoring respiration, U.S. Patent number: 4,308,872).

[0004] Multi-parameter wearable connected personal monitoring systems (for example: Zephyr Technology's BioHarness™, Qinetiq's Traintrak™, Weartech's GOW™) are already available on the market.

[0005] Respiratory Inductive Plethysmography is based on the analysis of the movement of a cross-section of the human torso with a low-resistance conductive loop using conductive textile or knitted warn, wire within an elastic band or braid, a loose wire within a textile tunnel or any conductive material in a configuration that makes it extensible. The extensibility is needed to follow the body as it changes shape due to breathing, movement, or other activities that can modify the body shape and volume.

[0006] Many patents and articles mention methods to use RIP sensors such as "Development of a respiratory inductive plethysmography module supporting multiple sensors for wearable systems" by Zhang Z, Zheng J, Wu H, Wang W, Wang B (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3545562/). It is hard to obtain good percentage of effective data as stated in an article entitled "A Wearable Respiration Monitoring System Based on Digital Respiratory Inductive Plethysmography" published at page 23 of the Vol. 3 No. 9/Sept. 2009 issue of the Bulletin of Advanced Technology research where only 83% of effectiveness only is achieved (http://www.siat.ac.cn/xscbw/xsqk/200911/W020091126365030914365.pdf).

[0008] Many types of oscillators, such as the Colpitts oscillator, have been proposed for RIP sensing and used with different configurations.

[0009] Noise and artifacts due to movement or other causes are common when RIP sensing is used in a garment or other wearable item. The system must be designed to tolerate noise and artifacts and be able to filter many of them to provide accurate breathing measurements.

[0010] Using data from one or many RIP sensors, analysis can provide major metrics such as Respiratory Rate, Tidal Volume and Minute ventilation, Fractional inspiratory time (T inhale, T exhale), and other information about the physiological and psychological state of the person or animal wearing the garment or the wearable item.

[0011] Determining signal quality and data quality for wearable sensors is very challenging. The assessment of signal and data quality is an important part of many high-level analysis algorithms, visual presentation of the data, and interpretation of the data in general.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In the appended drawings:

[0013] Figure 1: Colpitts optimal frequency range, shows the defined optimal frequency range of the Colpitts oscillator.

[0014] Figure 2: Battery powered Colpitts oscillator configuration for wearable RIP sensor, is a high level diagram showing how a battery power Colpitts oscillator. Figure 2 also shows the digital signal processing (DSP) that could be performed to provide useful data statistics and filtered signals.

[0015] Figure 3: Algorithm overview, is an example of the state machine for algorithm based on the RIP sensor data to extract the breathing rate, the minute ventilation and the tidal volume.

[0016] Figure 4: Inspiration and expiration detection with eye closing (inhibition period), is an example of how the wearable garment artifacts can be filtered out.

[0017] Figure 5 show a Smith chart result of the RIP sensor stimulated between 1MHz and 15 MHz and showing an excellent linearity with a resulting impedance around 2 micro Henry (uH)

[0018] Figure 6: Hexoskin system, shows garments that use the present system to connect textiles sensors for heart and breathing monitoring to an electronic device with an accelerometer and a Bluetooth wireless connection. The electronic device also contains analog and digital filters and amplifiers, a microprocessor device, solid-state memory storage, sensor circuits, power management circuits, buttons, and other circuits.

[0019] Figure 7: Multi-sensors intelligent shirt example, shows an example of a garment that includes RIP sensors, electrical, thermal, and optical sensors for cardiac monitoring, breathing monitoring, blood pressure monitoring, skin temperature and core temperature monitoring to an electronic device with position and movement sensors and a wireless data connection.

DETAILED DESCRIPTION

[0020] The foregoing and other features of the present invention will become more apparent upon reading of the following non-restrictive description of examples of implementation thereof, given by way of illustration only with reference to the accompanying drawings.

[0021] Low power sensing is a domain with many technological challenges for designers and manufacturers of e-textile solutions, intelligent garments, wearable sensors, and multi-parameter wearable connected personal monitoring systems.

[0022] In an aspect, the present specification describes a low resistivity impedance effort belt for using an insulated wire placed within a wearable garment or object. The impedance loop used is a wire strategically placed in a textile guide incorporated into the garment or object fabric (as exemplary shown in Figure 2). The loop goes from one connector contact to another going around the torso of the wearer.

[0023] As described in Figure 1, an optimal frequency range has been determined and implemented for the impedance loop. This range covers but is not restricted to the frequency band from 1MHz to 15MHz. This frequency range has been found to be optimal for the human body composition. The frequency is optimal for maximum precision for a garment or object equipped therewith.

[0024] The wearable device computes the statistics such as Breathing Rate or Breathing Volume or Tidal Volume or the fractional inspiration time.

[0025] The inductance variation due to movement of the RIP is very small but more efficient. Movement → delta Inductance → delta frequency → delta Amplitude → n bit sampling. The Colpitts in the frequency range from 1MHz to 15MHz is proven to be linear,

[0026] A Colpitts oscillator, invented in 1918 by American engineer Edwin H. Colpitts,[1] is one of a number of designs for LC oscillators, electronic oscillators that use a combination of inductors (L) and capacitors (C) to produce an oscillation at a certain frequency. The distinguishing feature of the Colpitts oscillator is that the feedback for the active device is taken from a voltage divider made of two capacitors in series across the inductor. (http://en.wikipedia.org/wiki/Colpitts_oscillator).

[0027] A change in the cross section of the body measured by the RIP sensor causes the Colpitts oscillator to change its oscillating frequency.

[0028] A digital and/or analog electronic circuit is used to measure the frequency, the change in frequency, and/or the rate of change of the frequency of the Colpitts oscillator.

[0029] To reduce power consumption further, the Colpitts oscillator can be turned ON and OFF many times per second. Sufficient ON time is needed to be able to sample the frequency of the Colpitts oscillator.

[0030] As described in Figure 4, two criteria are considered to detect inspiration/expiration. One is the adaptive filter threshold; the other is the eye closing (the inhibition period). In Figure 4,, an expiration is found when the condition (point A, minimum). It also applies to detection of inspiration but searching for maximum.

[0031] One example of adaptive Threshold_resp as in Figure 4:

- 25% of the average duration of the 4 last expirations
- 5 ≥ Threshold_resp ≥ 50

[0032] One example of adaptive Eye_closing as in Figure 4:

- 25% of the average duration of the 4 last respiration (i.e. inspiration + expiration)
- 16 ≥ Eye_closing ≥ 256 (@128 Hz, thus 0.125-2 s)

[0033] The algorithm described is Figure 3 shows an example of adaptive filtering with 2 RIP bands, using a ponderated sum of the thoracic and abdominal signal for inspiration/expiration detection usage to extract minute ventilation, breathing rate, tidal volume and Fractional inspiratory time (INSP: T inhale, EXP: T exhale). RESP is the sensing input coming from the Colpitts oscillator. Signal quality assessment is performed to validate input regarding the noise status of the sensor, its baseline linearity check and general status such connector connect/disconnect detection.

[0034] Figure 6 shows an example of the RIP sensor integration in the wearable system. The sensors are normally passive and become active only once they are connected to the active electronic analog front end. 2 RIP sensors are placed on a shirt, one on the torso one on the abdomen. 3 textile electrodes are also placed, 1 differential inputs (ECG lead I) and one reference. All sensors electrical signal lines are interconnected through the connector to the small wireless apparatus. An apparatus comprising a 3-axis accelerometer motion sensor, local memory for data, processing capabilities to analyze data in real-time, and Bluetooth communication capabilities, is used to communicate with smart phones and computers. The data is processed and analyzed in the device in order to transmit only what is important to minimize power consumption. The smart phone and computer network connectivity make possible remote server communication, which can provide automatic physiological data analysis services and help with the interpretation of physiological signals.

[0035] Figure 7 is another wearable garment example where many more sensors are integrated into the fabric. For each sensor a different wiring technique can be used such as insulated wires, knitted conductive fibres, laminated conductive textile, optic fibre and/or polymer. Sensors can be strategically placed to perform good quality biometric measurements. Figure 7 shows a 2 RIP bands sensor, a 4 textile electrodes ECG, a caught pressure sensor on the left arm, 4 temperature sensors, 3 position and orientation sensors, and an optical spectroscopy sensor. Other type of sensors such as galvanic skin response (GSR), stretch sensors for structural sensing and others.

[0036] Although the present low power oscillator RIP sensors for wearable intelligent garment have been described in the foregoing description by way of illustrative embodiments thereof, these embodiments can be modified at will, within the scope of the appended claims without departing from the spirit and nature of the appended claims.

What is claimed is:

1. A respiratory inductance plethysmography (RIP) sensor connected to a washable interconnection for interconnecting wires to an oscillator circuit comprising:
   a. a wire loop in a garment connected to an electronic device using a Colpitts oscillator in the frequency band of 1MHz to 15MHz, and
   b. The wire loop may be connected to the electronic device using a connector that may be washable or water resistant.

2. The wire loop can be constructed using any conductive material in a configuration that makes it extensible.

3. The oscillator and/or the rest of the electronic device may be powered by a battery or another source of electric power.

4. The oscillator frequency or frequency change can be measured using an analog and/or digital electronic circuit.

5. The oscillator can be turned ON and OFF many times per second according to frequency sampling to save electric power.

6. The oscillator being connected to a digital processing device that convert its analog information into digital information and applies one or many algorithms to analyze the information.

7. Using data from one or many RIP sensors, analysis can provide standard breathing metrics such as Respiratory Rate, Tidal Volume and Minute ventilation, Fractional inspiratory time (T inhale, T exhale).

8. The analysis methods described in Figure 3 and Figure 4.

9. Using data from one or many RIP sensors, analysis can also provide metrics to detect and characterize talking, laughing, crying, hiccups, coughing, asthma, apnea including sleep apnea and stress related apnea, relaxation exercise, breathing cycle symmetry, pulmonary diseases and other physical conditions.

10. Using data from one or many RIP sensors, analysis can also provide metrics to characterize heart activity including heart rate, many types of movements and activities including walking and running.

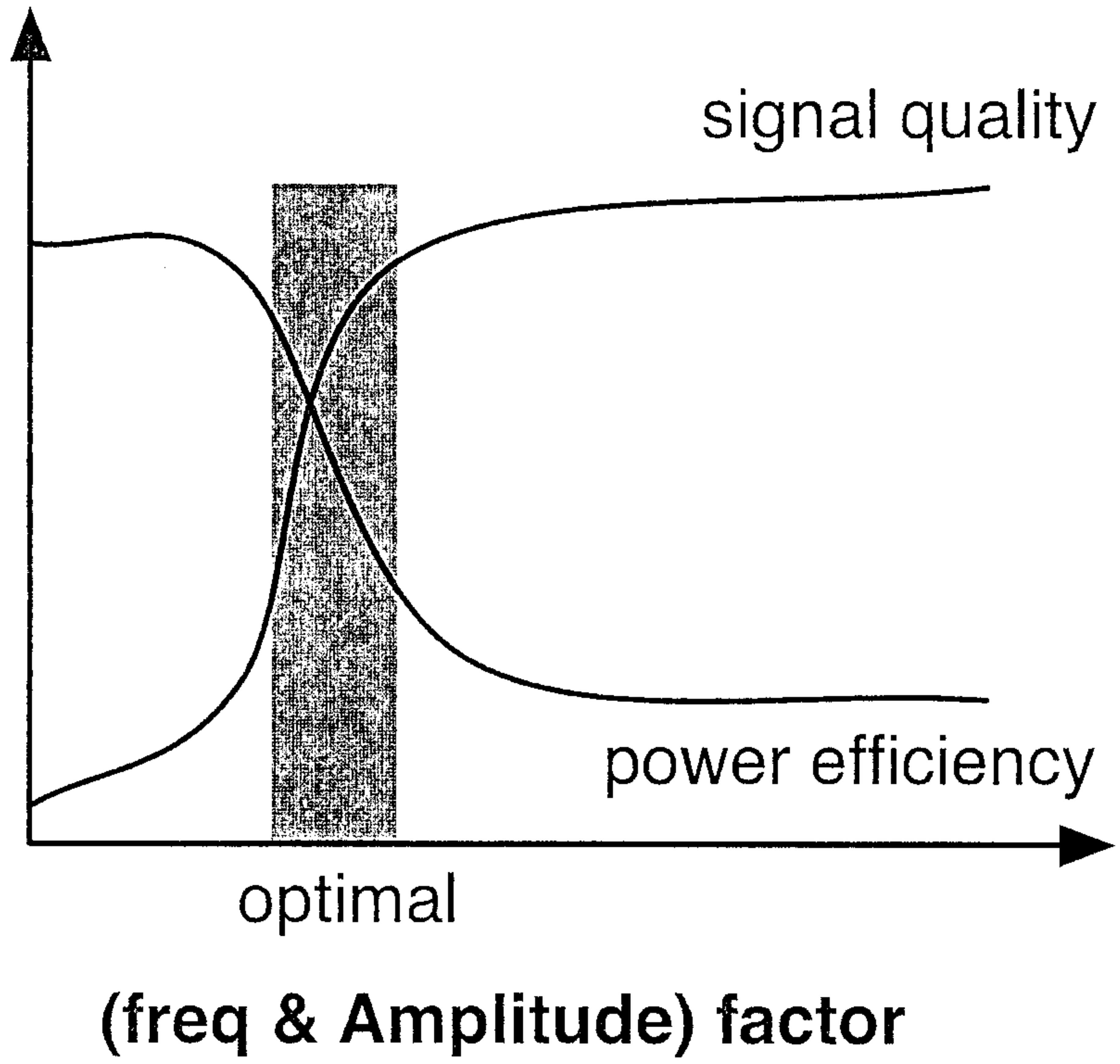

Figure 1: Colpitts optimal frequency range

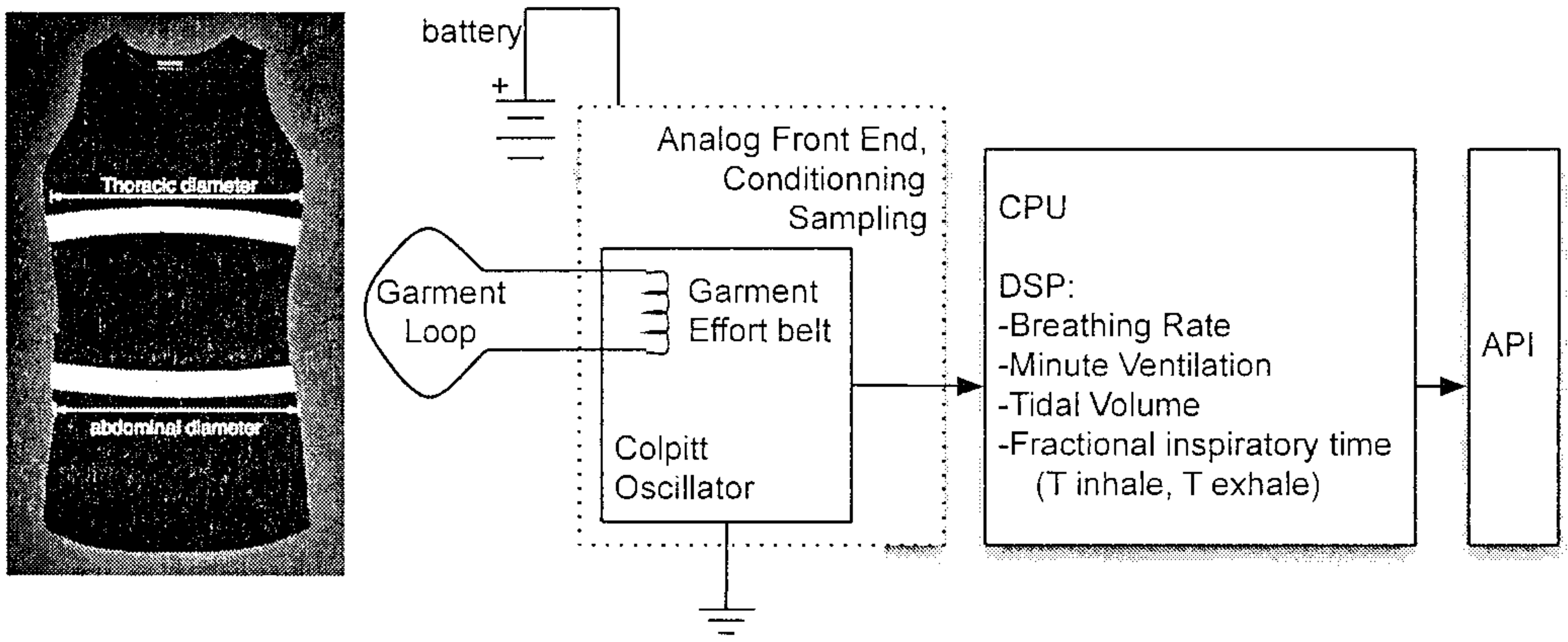

Figure 2: Battery powered Colpitts oscillator configuration for wearable RIP sensor

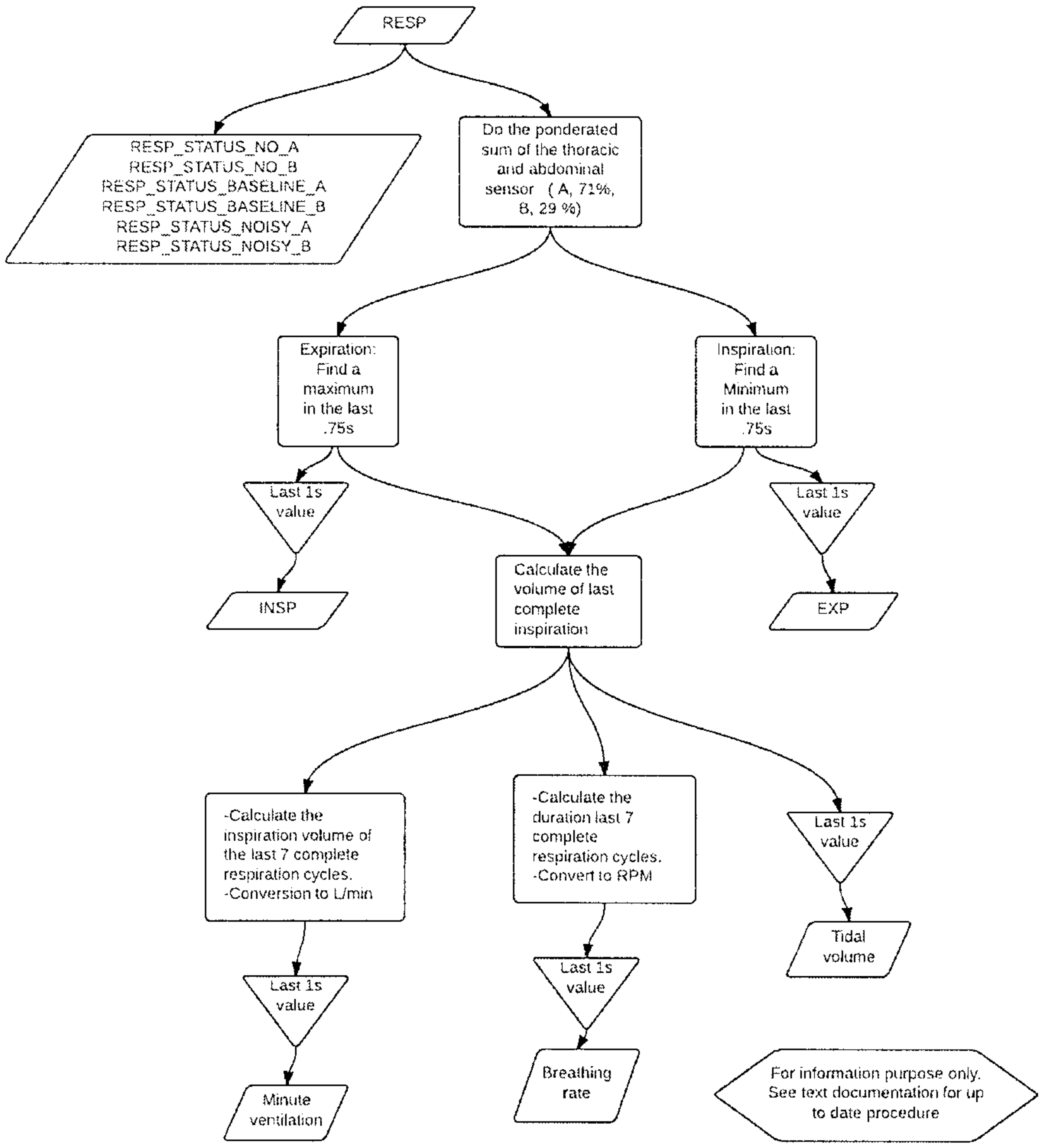

Figure 3: Algorithm overview

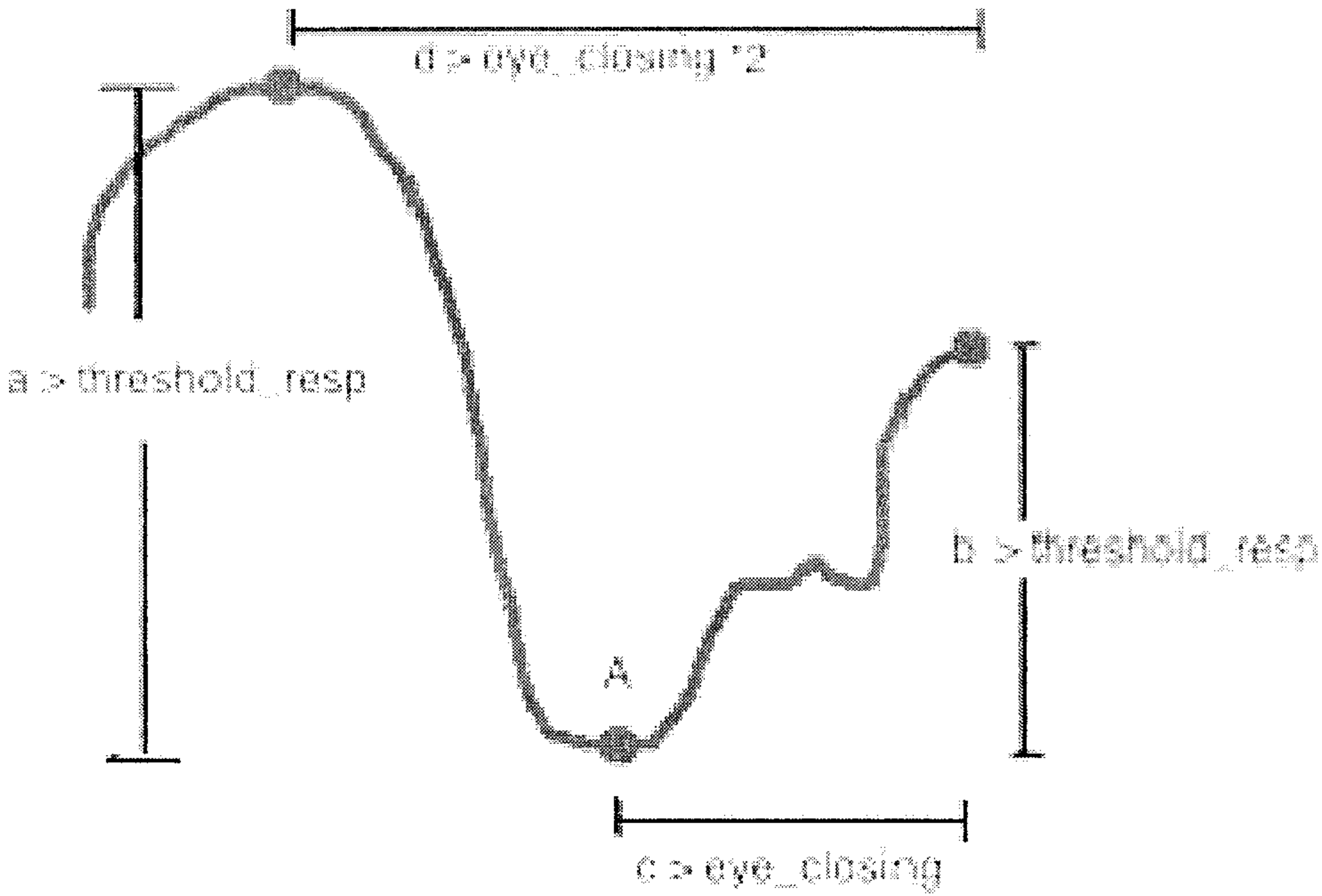

Figure 4: Inspiration and expiration detection with eye closing (inhibition period)

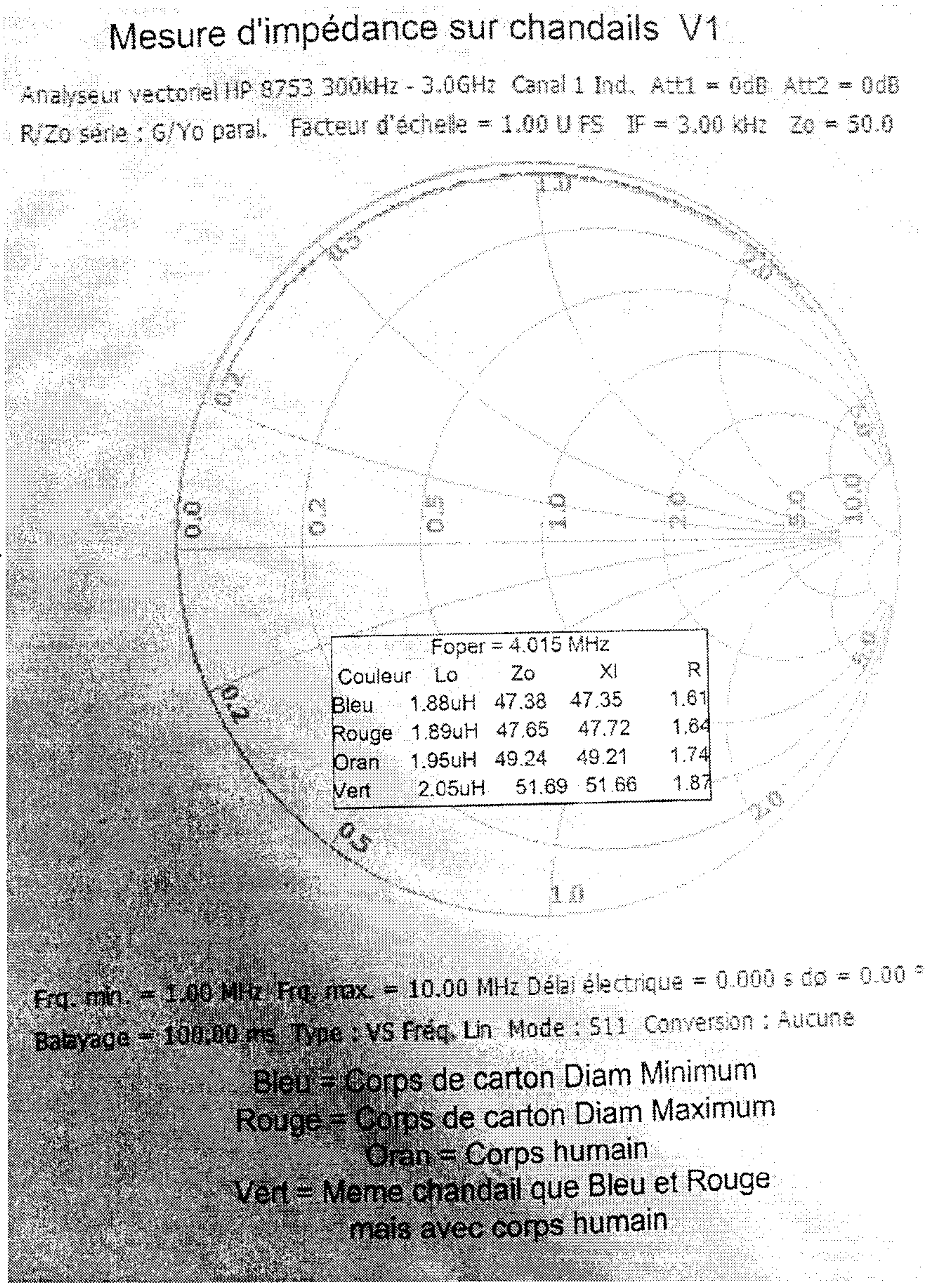

Figure 5: Smith Chart of a wearable RIP sensor

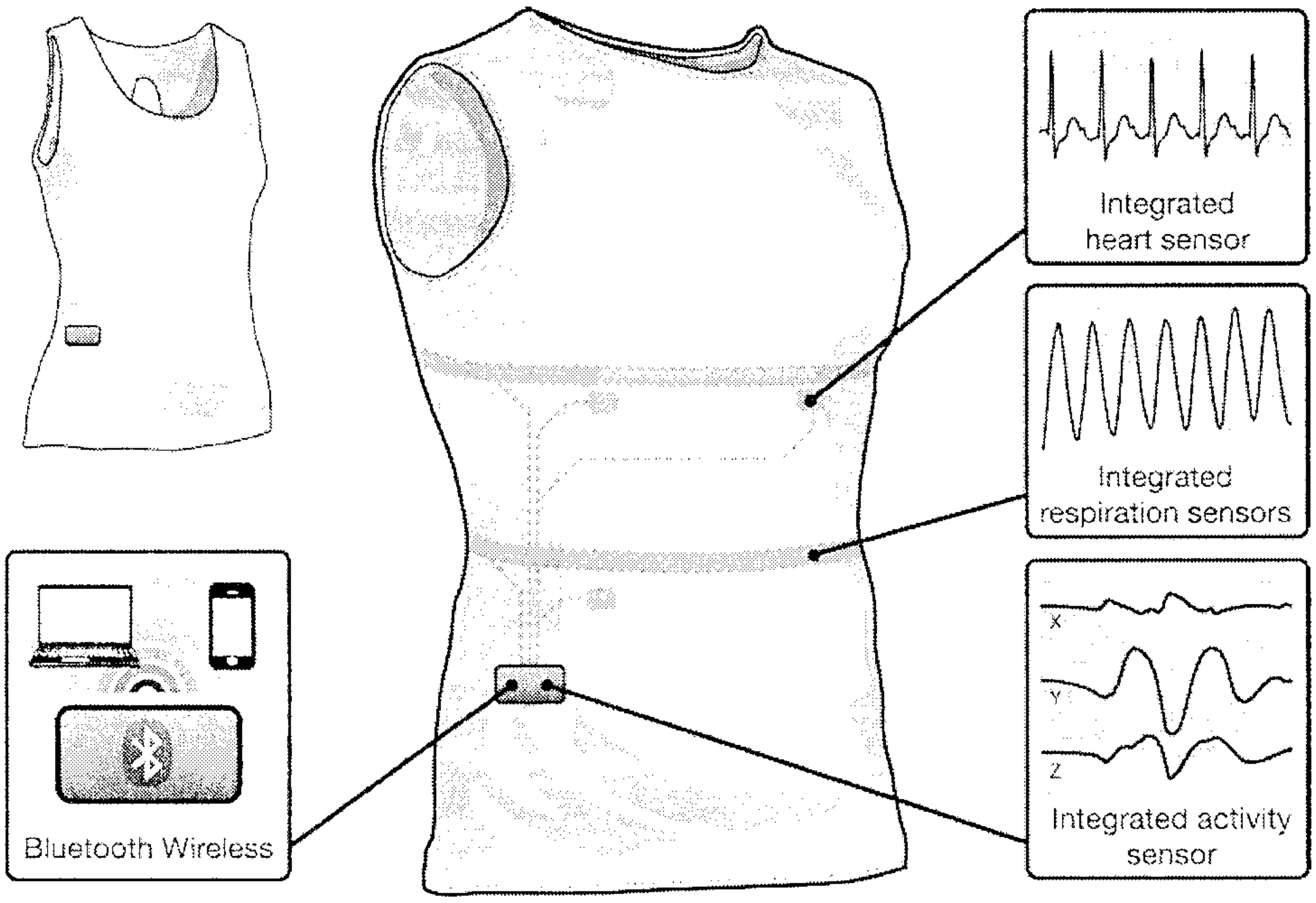

Figure 6: Hexoskin system

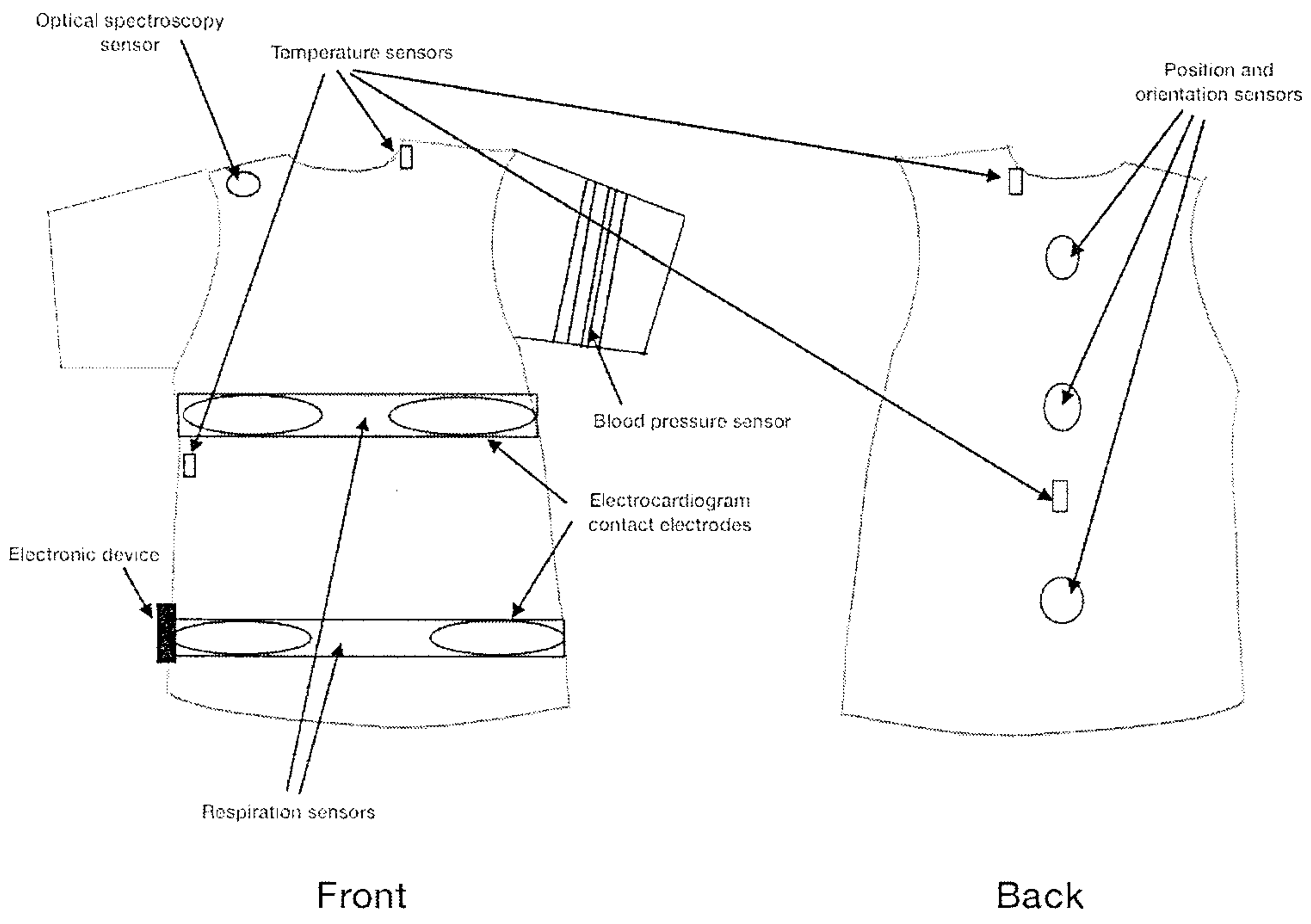

Figure 7: Multi-sensors intelligent shirt example