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(54) Title: A METHOD AND SYSTEM FOR DETERMINING THE STATE OF A PERSON

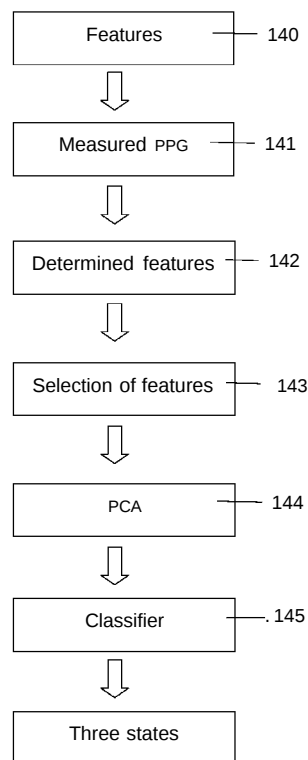


Fig. 9

(57) Abstract: According to the present invention there is provided a method for determining the state of a person, comprising the steps of, sensing a pulse of the person using a photoplethysmo graph (PPG) sensor; generating a digital pulse waveform which represents the sensed pulse; determining one or more features from the digital pulse waveform; using the one or more features to determine the state of a person being either or both of: 1) a mix of the three heart, breathing and relaxing conditions; or 2) a mix of the three Tibetan Ty-pologies: Lung, Tripa and Beken.

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A method and system for determining the state of a person

Field of the invention

The present invention concerns a method and system for determining the state of a person; and in particular to a method and system for determining the Tibetan state and/or state of the body and mind of a person in which features of digital pulse waveform which is representative of the pulse of a person, is used to automatically determine the state of the person.

Description of related art

Western science has developed a strong analytical understanding of the body and the mind, more like two separate entities that sometimes interfere with each other in a complex still unknown way. Techniques such as digital pulse wave (DPW) sensing and processing are used for estimating vital signs such as blood pressure, arterial compliance, pulse wave transit time, oxygen, and pulse heart rate. Amongst the most popular sensors are those based on optical light at various wavelengths and are called photoplethysmographs (PPG).

Traditional Tibetan Medicine (TTM), like most Traditional Medicine systems such as Chinese (TCM) and Ayurvedic (TAM), has developed an empirical knowledge of the body-mind complex (BMC) since thousands of years. Of particular interest for this research is one of their diagnosis systems based on blood pulse wave finger sensing: using several fingers placed on certain parts of the body, the medical doctor is able to identify the type of disorder the patient is suffering from. The disorder can have external origins such as seasonal changes, food poisoning, injuries; and can also have internal causes such as mental stress, anxiety, and so on. These medical systems are holistic by nature, seeing the BMC as a whole, and thus also provide treatments that harmonize the BMC.

According to TTM, each person is qualified with three BMC characteristics called Typologies. The Typology of a person can be of three

different aspects according to Traditional Tibetan Pulse reading: wind (Lung), bile (Tripa) and phlegm (Beken).

Each person possesses a specific Typology at a certain age. These Typologies evolve with time, external conditions and internal conditions, i.e. young babies tend to be more phlegm, adult more bile and elderly more wind. The Typology of a person can change with the seasons, with the night and day cycle, breathing cycle, and/or even with the heart pulse cycle. Each person possesses the three Typologies in a certain ratio at any particular time.

These three typologies play an important role in the TTM system of diagnosis and treatment. The tendency of a person to be of a certain type tells the traditional doctor about her physical and mental condition, which in turn is used in further diagnosis refinement. Pathologies reflect the fact that the three Typologies of a person are in a state of imbalance; to give a precise example, if a person is predominantly bile type but presents conditions of flu, we can say that she has developed a phlegm disorder.

There is a correspondence between the three Typologies and physiological, psychological, energy functions and the senses/sense organs. These correspondences are helpful to cross the bridge between Eastern and Western way of thinking, and also show that the BMC forms a whole. The basic correspondances are shown in Table 1.

	<i>Lung</i>	<i>Tripa</i>	<i>Beken</i>
<i>Physiology</i>	Nervous system, Blood circulation, Lymphatic circulation, Tissue growing, Reproduction, Excretion	Digestion, Skin coloring	Immune system, Bone structure, Joins lubrication
<i>Psychology</i>	Cognition, Anxiety, Distress, Fear, Instability	Creativity, Desire, Anger, Joy, Impulsiveness, Extraversion	Tolerance, Generosity, Tranquility, Introversion
<i>Sense/Organ</i>	Touch (Skin), Hearing (Ears)	Vision (Eyes)	Taste (Tongue), Smell (Nose)
<i>Energy</i>	Movement, Creation, Birth, Aging, Death	Transformation, Discrimination	Structure, Stability, Construction/Cohesion

Table 1 : Correspondences between Western and Eastern medical systems

To date, to determine the typology of a person, Traditional Tibetan Pulse (TTP) reading is mainly used. The TTP can be measured sequentially

with one finger at a time as well as simultaneously with the three fingers (as shown in Figure 1a). The TTP is traditionally recorded with three fingers (index, middle and ring) of the doctor (see Figure 1b), placed along the radial artery of the wrist: first on the left/right wrist for male/female and
 5 second on the right/left wrist for male/female. Each fingertip, index, middle and ring, assess different parts of the body: upper, middle and lower respectively. The index is always placed toward the thumb in a flat position so that each side of the fingertip can sense the pulse wave. The mapping of the organs senses with the fingers and the fingers position is displayed in
 10 Figure 1c. Figure 1c shows that TTP reading can identify and diagnose 12 organs using the two wrists of the patient: $2(\text{wrist}) \times 2(\text{finger's side}) \times 3(\text{fingers})$. Note that male and female have different wrist-to-organ mapping.

The doctor determines the typology of the patient on the basis of the
 15 characteristics of the pulse of the patient which the doctor feels through the three fingers. The following correspondence between the Typology and the pulse characteristics can be made as follows:

- wind (**Lung**): Rough, quick, empty, floating with intermittent beats,
- bile (**Tripa**): Sharp, rolling, strong, fast, overflowing with taut beats,
- 20 • phlegm (**Beken**): Sunken, slow with very weak beats,

To date TTP reading can only be performed by skilled doctors who simply place their fingers on some vital patient's body locations to feel and 'listen to' the pulse of the patient; the doctor then draw a conclusion as to the Typology of the patient based on characteristics of the pulse he/she has
 25 felt. However, pulse reading in this manner requires many years of training and experience. There is no means provided to date which would enable an unskilled person to perform TTP reading.

Summary

It is an aim of the present invention to mitigate or obviate at least
 30 some of the aforementioned disadvantages. According to the present invention there is provided a method for determining the state of a person,

comprising the steps of: sensing a pulse of the person using a photoplethysmograph (PPG) sensor; generating a digital pulse waveform (DPW) which represents the sensed pulse; determining one or more features from the DPW; and using the one or more features to determine
5 the state of the person.

The state of the person may comprise at least one of: the heart condition, breathing condition and/or relaxing condition of the person. The state of the person may be the Tibetan state of the person. The Tibetan state of the person may comprise a ratio of wind (lung), bile (Tripa) and
10 phlegm (Beken) Typology that the person possesses.

Few parameters such as age, gender, height and weight can be used in addition to refine the computation of the state. The classical state of the person including the heart condition, breathing condition and relaxing condition of the person and/or the Tibetan state of the person (i.e. the
15 Typology of the person) can be determined automatically.

The heart condition, breathing condition, relaxing conditions, the determined ratio of wind (Lung), bile (Tripa) and phlegm (Beken) Typology of the person may be represented either on a digital display by a set of user chosen color tones, images or other suitable visual information; or on an
20 analogue display using mechanical means.

Determining the heart condition, breathing condition and relaxing condition of the person can comprise determining values each of which is representative of the heart condition, breathing condition and relaxing condition of the person. Determining a value which is representative of
25 the heart condition of the person can be determined using a measurement of the heart rate and heart rate variability of the person. Determining a value which is representative of the breathing condition of the person can be determined using a measurement of the pulse wave envelope and Peak-to-Peak (PP) intervals, of the person. Determining a value which is
30 representative of the relaxed condition of the person can be determined using a measurement of the heart rate variability and spectral entropy of

the PP, of the person. The value which is representative of the heart condition, of the breathing condition, and of the relaxed condition of the person can be displayed on a display only if the measured movement of the person is below the threshold level of movement. Moreover, the value
 5 which is representative of the heart condition, of the breathing condition, and of the relaxed condition of the person can be displayed on a display continuously or only on demand. The DPW is preferably generated by PPG signals which are output from the PPG sensor when the PPG sensor is sensing the pulse of the person. The one or more features may comprise at
 10 least one of, heart rate variability, spectral entropy and/or undulations level indices. The one or more features may comprise at least one of, the pulse wave envelope, peak-to-peak (PP) intervals, heart rate, heart rate variability indices in the frequency domain and/or spectral entropy of the PP intervals.

The one or more features may comprise, at least one of, the mean
 15 value of PP (R_m), normalized variance of PP (R_v), normalized undulation level of the heart pulse wave (EUL), normalized spectral entropy of the heart pulse wave (ESEh), Lempel-Ziv complexity of the heart pulse wave (PW) (LZrr) and/or normalized breathing frequency (BF). The method may comprise the step of forming surrogates of the one or more parameters.

20 The pulse of the person can be sensed at one of the locations of the person comprising at least the wrist, hand, fingers and ears of a person, and the method can comprise securing the PPG sensor around the wrist, hand, fingers or ears of a person such that the PPG sensor is arranged to sense pulse at the wrist, hand, fingers or ears of the person. The method
 25 can comprise the step of sensing the pulse at the left wrist, hand or fingers of the person or at the left ear of the person, such as to generate a first DPW, and sensing the pulse at the right wrist, hand or fingers of the person or at the right ear of the person, such as to generate a second DPW. The method can further comprise determining one or more features of each of
 30 the first and second DPW; and using the one or more features to determine the ratio of wind, bile and phlegm Typology that the person possesses

Alternatively, the method can comprise the step of sensing the pulse at one of the left and right wrist, hand, fingers and ear of the person respectively; generating a corresponding DPW; determining one or more features of the corresponding DPW; and using the one or more features in combination with a set of reference features extracted from offline population average to determine the ratio of wind, bile and phlegm Typology.

The method can further comprise the step of determining the difference between the one or more features of each of the first and second DPW. The determined difference can be used for determining the ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology.

The method may further comprise the step of measuring the movement of the person. The movement of the person can be measured using one or more accelerometers. Preferably the movement of the person is continuously measured. The method can comprise the step of comparing the measured movement of the person to a threshold level of movement, and determining one or more features of the DPW only if the measured movement of the person is below the threshold level of movement. The measured movement of the person can be continuously displayed on a display. Alternatively the measured movement of the person can be displayed on the display only on demand.

The method can further comprise determining a quality index value which is representative of the quality of the PPG signal, and comparing the quality index value to a threshold quality index value. The step of determining the one or more parameters of the DPW can be performed only if determining a quality index value is greater than the threshold quality index value.

The method can comprise the step of streaming one or more features of the DPW and the DPW to an operating system. The operating system can be configured to use the one or more features to determine the ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person

possesses. The operating system may comprise a display which can display one or more measurements or results e.g. to display the determined ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person possesses. The operating system may comprise the display of the heart,
5 breathing and relaxing condition. The operating system may further comprise a storage means for storing data.

The method may further comprise the step of selecting a subgroup of features from the one or more features from the determined one or more features of the DPW; and using the selecting subgroup of features, to
10 determine the ratio of wind, bile and phlegm Typology that the person possesses.

The method may further comprise the step of performing principal component analysis on the one or more features to extract salient information from the features and separate them for further
15 classification. The step of performing principal component analysis on the one or more features may be carried out to generate feature clusters which are representative of the wind (lung), bile (Tripa) and phlegm (Beken) Typology. Preferably the principal component analysis is performed in state space.

20 The method may further comprise the step of identifying which cluster corresponds to wind (lung), bile (Tripa) and phlegm (Beken) Typology respectively. The Typology of the person being determined by a Tibetan doctor in order to perform the classification of the feature clusters.

The method may further comprise the step of separating clusters
25 (classification) which have been determined during principal component analysis and which are representative of the wind (lung), bile (Tripa) and phlegm (Beken) typology respectively, from each other. Each cluster corresponds to either of the wind (lung), bile (Tripa) and phlegm (Beken) Typology as determined by the Tibetan doctor.

- The method may further comprise the step of using a classifier which has been trained to map the different clusters into the Tibetan doctor typology as determined by the Tibetan doctor. The classifier may be of Neural Network, Linear Discriminant or similar architecture. The method
- 5 may further comprise the step of processing the DPW to reduce artefacts. For example, a linear filter may be applied to the DPW to reduce artefacts in the DPW. The method may further comprise the step of using principal component analysis on the DPW, with selection of the components which have a frequency within a predefined range.
- 10 The method may be performed while the person is sleeping to determine a first ratio of the wind (lung), bile (Tripa) and phlegm (Beken) typology of a person, and the method may be performed while the person is awake to determine a second ratio of the wind (lung), bile (Tripa) and phlegm (Beken) Typology of a person, and the method may further
- 15 comprise the step of detecting changes between the first and second determined ratios. The method may contains information extracted from the three classic conditions of heart, breathing and relaxing while the person is sleeping to determine sleep disordered breathing patterns.

- According to a further aspect of the present invention there is
- 20 provided a system for determining the state of a person, comprising, a PPG sensor which is configured to generate a DPW which represents a sensed pulse of the person; a means for determining one or more features of the DPW; a means for determining the state (classic and/or Tibetan state) of the person from the one or more parameters of the DPW.

- 25 The means for determining the state of the person may comprises a means for determining the heart condition, breathing condition and/or relaxing condition of the person from the one or more features of the DPW. The means for determining the state of the person may comprises a means for determining the ratio of wind, bile and phlegm Typologies that
- 30 the person possesses from the one or more features of the DPW.

The DPW is preferably generated by PPG signals which are output from the PPG sensor. The PPG sensor may be configured to be worn about one of the wrist, hand, fingers and ears of a person such that the PPG sensor is arranged so sense pulse at the wrist, hand, fingers or ears of the
5 person. The sensor may be further configured to measure the movement of the person. For example, the sensor may have one or more accelerometers which are operable to measure the movement of the person.

The system may further comprise a control module which is configured to, receive the measured movement of the person, compare the measured
10 movement of the person to a threshold movement value, and to selectively effect the generation of the DPW using a PPG signal output from the PPG sensor only if the measured movement of the person is below the threshold movement value. The control module can be further configured to receive a PPG signal output from the PPG sensor, and to calculate a quality index
15 value which is representative of the quality of the PPG signal, compare the quality index value to a threshold quality index value and to a selectively effect the generation of the DPW using the PPG signal output from the PPG sensor only if the quality index value is greater than threshold quality index value.

20 The system can further comprise a streaming unit which is configured to communicate wirelessly with a processing means for display and which defines means for determining said one or more features of the DPW and wherein the processing means further defines the mean for determining the ratio of wind, bile and phlegm typology that the person possesses from
25 the one or more features of the DPW. The system can further comprise an analog display unit which is capable of showing the state of the person in a holistic way by means of mechanisms.

The system may comprise a means with is configured to perform any of the steps mentioned in the above method methods.

Brief Description of the Drawings

The invention will be better understood with the aid of the description of an embodiment given by way of example only and illustrated by the figures, in which:

5 Fig. 1a shown the position of the fingers of the traditional doctor when performing pulse reading; Fig. 1b shows the finger which are used to perform pulse reading; Fig. 1c show the mapping of organs to the different locations on the wrist of the patient;

 Fig. 2 provides a block diagram of aDPW system, according to an
10 embodiment;

 Figs. 3a and 3b show clusters, which result from principal component analysis in state space, which represent the Typology of the patient; Fig 3a show clusters derived from measurements taken on the left and right wrists of a patient and Fig 3b are clusters derived from the values
15 of left minus right wrist measurements;

 Fig.4a shows ROC curves for QNN^{FP} (FP refers to First Pass, see below for detailed explanations) with manual feature selection, Fig.4b shows ROC curves for QNN^{FP} with mRMR feature selection;

 Fig. 5ashows the ROC curves for QNN^{SP} (SP refers to Second Pass, see below for detailed explanations) with manual feature selection, while
20 fig. 5bshows the ROC curves for QNN^{SP} with mRMR feature selection;

 Figs.6, 7 and 8 present feature statistics for a number of patients, for each Typology.

 Fig 9 provides a flow chart which summaries the steps involved in
25 a method according to an embodiment of the present invention;

 Figs. 10a, b, and c each illustrate a flow diagram of the steps involved in a method according to an embodiment of the present invention;

Fig. 11 represents a qualitative correspondence between DPW and TTP measures, according to an embodiment.

Detailed Description of possible embodiments

In Traditional Chinese Medicine, it is said that 27 pulse wave patterns can be recognised for diagnosis and prognosis. They sense different qualities such as: strength, trend, tension, shape, width, rhythm, rate, length. TTM uses mainly the Chinese system of pulse reading and we can therefore base our TTP classes on these qualities: shape, tension, width, length, amplitude, rate, regularity. Each Typology is directly linked with a subset of these qualities. Concerning the pulse, the following correspondence between the Typology and the TTP features can be made:

- *wind (Lung)*: Rough, quick, empty, floating with intermittent beats,
- *bile (Tripa)*: Sharp, rolling, strong, fast, overflowing with taut beats,
- *phlegm (Beken)*: Sunken, slow with very weak beats

The difficulty in interpreting the DPW thus becomes obvious: how to translate a descriptive quality (the TTP) into a quantitative measure using the DPW features such as rising and falling transition time, amplitude, frequency and/or time-frequency content. This is called hereafter the T2D mapping.

An automatic method for Typology assessment using digital signal processing and classification methods requires objective measures. Table 2 in Fig. 11 represents a qualitative correspondence between DPW and TTP measures. In the Table 2, there is also provided some archetypal qualitative pulse wave forms for each TTP measure. The goal for using TTP measures for the Traditional Tibetan practitioner is to classify each of the Typologies and also to tentatively describe them in a qualitative verbal way. This is important to map the Typologies into some numerical measures computable with the DPW as it will be shown below.

This embodiment of the sensing system of the present invention is configured for single finger position measurement at a time. In order to simplify analysis, the sensor is configured to measure at the index finger position only (i.e. the position on the wrist of the subject at which the doctor's index finger would be positioned when performing TTP reading).
5 The corresponding location is the one proximal to the thumb as can be seen in Figure 1(a). This location is particularly suited to analyze the properties related to the heart, lungs, small and large intestines.

The sensor is positioned on the radial artery in a similar way a Tibetan
10 doctor would sense the pulse until the signal shows some stability as displayed on the screen of the computer running the recording software. Once an optimal position has been found, the sensor is maintained with a wrist band during the duration of the recording. The subject is then asked to avoid moving, clinching the fist and eventually talking, while breathing
15 normally and in a relaxed way.

The DPW Recording Instrument The measure of the pulse wave should be done preferably using a pressure sensor. The reason for this is that the qualities of the pulse wave sensed by the doctor's fingers depends on the applied pressure and corresponds to different parts of the body. In Figure 1
20 the fingers distal from the thumb must apply more pressure and sense deeper tissues and lower organs.

Measurements performed by the DPW recording system rely on the so-called Photo-Plethysmographic (PPG) principal. PPG is an optical non-invasive technology allowing the assessment of information related to
25 subcutaneous blood circulation. By illuminating a living tissue with an infrared light source, PPG obtains estimates on both arterial pulsatility and arterial blood content. PPG measurements setups consist thus of a light source and a photo-receptor. The main advantage of this PPG-based DPW system is its potential for high integration in a small device, comfort and
30 low cost which makes it attractive as a portable low-cost health monitoring system. The placement of the sensor can be preferably on the wrist radial

artery or finger tips. The sensor can also be placed on the ear lobe or any suitable place where the pulsatile heart pulse wave can manifest.

A block diagram describing the DPW recording system is provided in Figure 2. The system comprises an optical probe 10, an electronics box 13, and a laptop 14. The optical probe includes a Light Emitting Diode (LED) 11 or any adequate source of light and a photodiode 12 or any photosensitive device. The electronics box includes an analog front-end (performing the continuous removal of ambient light reaching the photo-diode, and acquiring the raw optical signals at a minimal rate of 20 times per second (sampling frequency $f_s = 20\text{Hz}$). The DPW is generated from the PPG signal using analog filters, Analogue to Digital Converters and Digital filtering to remove wandering trends and high frequency content of the PPG signal.

Digital Pulse Wave Processing The DPW qualities can be described with: Rhythmicity and Stability. Rhythmicity and Stability are explained hereafter. Rhythmicity is linked with the regularity of the pulse repetitive frequency. This is well known in cardiovascular research that the heart beat exhibit a wide variety of rhythms, some linked with short term behaviour of the autonomic nervous system and the voluntary movement of the thoracic chest; some with long term behaviour of hormonal regulation and gas exchanges. Rhythmicity can be partially still reasonably well described using Heart Rate Variability (HRV).

Stability is linked with amplitude and frequency fluctuations or modulation of the pulse wave. This behaviour can be related also with the frequency modulation of the pulse wave, leading to AM/FM modulation as seen exemplarily in the so-called Respiratory Sinus Arrhythmia phenomena. Local vasoconstriction and/or dilation of the vessels can also manifest in amplitude modulation. Stability can be partially described using Spectral Entropy (SE) and Undulation Level (UL) indices.

The reasons for focusing on Heart Rate Variability (HRV) Spectral Entropy (SE) and Undulation Level (UL) indices measures is that 1) they are

quite robust to a wide variety of perturbations, 2) they are computable with short time series, 3) they are easy to understand.

Each of these DPW Rhythmicity and Stability qualities are further linked with quantitative measures called DPW features and are summarized in the Table 3. The normalization of most of the features is preferred so as to have a well-conditioned feature space when it comes to carrying out a classification step. Details of how normalization is carried out are provided in Table 4. The $DPW(t)$ signal can be coarsely separated into two components: 1) a Heart Pulse Wave ($HPW(t)$) and 2) a Breathing Pulse Wave ($BPW(t)$) which can be symbolized as:

$$DPW = HPW \oplus BPW \quad (1)$$

The $HPW(t)$ is itself modulated by the respiratory system as discussed in the Stability quality, which contains both a nervous and mechanical origin. The $BPW(t)$ is solely originating from the mechanical effect of breathing: i.e. the change of pressures in the vascular system and heart chambers due to the diaphragm and chest movements.

Both the qualities Rhythmicity and Stability, and their numerical implementations as shown in Table 3, could eventually be mapped to the qualities of the pulse wave as described in Table 2 (Fig. 11) (this is the D2T mapping). However, D2T mapping may not be required when linking directly the DPW measures with the three Typologies, understanding that these Typologies are themselves described by the TTP measures as shown in Table 2 (Fig. 11).

Pre-processing The signal coming out of the DPW sensor contains a large DC offset and some slow drift. Additionally, it contains movement artefacts. The pre-processing thus comprises first using DC offset and slow drift removal in the first instance, and second applying a gentle linear filtering to reduce the effects of the movement artefacts still keeping the main features of the pulse wave. These two steps are described hereafter.

DPW Qualities	DPW Features	
Rhythmicity	Heart Rate Variability	Normalized Low Frequency (<i>LF</i>)
		Normalized High Frequency (<i>HF</i>)
		Normalized Variance of PP (<i>Rv</i>)
		Mean of PP (<i>Rm</i>)
		Normalized Breathing frequency (<i>BF</i>)
Stability	Normalized Enhanced Undulation Level of HPW(<i>EUL</i>)	
	Normalized Bandwidth of HPW(<i>BWh</i>)	
	Normalized Enhanced Spectral Entropy of HPW(<i>ESEh</i>)	
	Lempel-Ziv Complexity of Heart PW (<i>LZrr</i>)	

Table 3: DPW Qualities and Features

Feature	Normalization	Normalization Factor
<i>LF(HF)</i>	$LF(HF)/Var_{Tot}$	Var_{Tot} is the total power of the heart related pulse wave
<i>Rv</i>	$Rv/R_{2,MaxMin}$	$R_{MaxMin} = (max(PP) - min(PP))/2$
<i>BWh</i>	BWh/BWh_{Max}	$BWh_{Max} = fc_H - fc_L$, fc_H and fc_L are the cut-off frequencies of the Butterworth filter used to extract <i>HPW(t)</i>
<i>BF</i>	BF/BWb_{Max}	$BWb_{Max} = fc_H - fc_L$, fc_H and fc_L are the cut-off frequencies of the Butterworth filter used to extract <i>BPW(t)</i>
<i>EUL</i>	<i>Sat(EUL)</i>	The <i>Sat()</i> function is a hard thresholding function between 0 and 1. The <i>EUL</i> should be bounded in [0,1], but occasionally overshoot for some signals.

Table 4: Normalization

Principal Component Filtering with Frequency Selection

The first pre-processing is performed with a quadratic detrending, while the second uses a Principal Component Analysis in State Space (PCA-SS) method together with an additional frequency selection (PCA Freq). This pre-
 5 processing is performed using a state space embedding of the time series with an embedding dimension of $m=40$ and reconstruction lag $\neq 1$ sample. The maximum number of components to be used is limited to be the first 8
 10 corresponding to the largest eigenvalues of the trajectory matrix, thus reducing the amplitude of the high frequencies. It is further selected from these components those for which the spectral content has a maximum between 0.05Hz and 12Hz. This choice of the frequency band corresponds to the physiologically plausible content of the heart and respiration three first main harmonics.

Artefact Reduction

The $DPW(t)$ is subject to movement and muscle
 15 artefacts. These artefacts appear as brief signals of high amplitude and would bias the statistics which will be performed if they are not removed. These artefacts have a very different influence on the statistics than time-amplitude-uniform noise sources. These artefacts are thus removed using digital signal processing techniques. A wavelet based artefact detection
 20 and reduction methods could be used. Wavelet analysis is particularly well suited for artefact detection as it can precisely localize it in the time and scale domains simultaneously. The artefact shows up in some scales of a wavelet transform W as a set of larger components. In order to detect these scales contaminated by the artefact, an *Artefactness* degree is defined as
 25 follows:

$$A(s) = 2 \text{ Sigmas} / (\max(\text{abs}(s)) - \min(\text{abs}(s))) \quad (2)$$

where Sigmas is the standard deviation of a signal s . It is guarantee that $A \in [0,1]$ with a value closer to 0 when the artefact is large and close to 1 when the artefact is small. The artefact removal technique thus takes the
 30 form:

$$c_j = S_j[W(x)] \quad (3)$$

$$a_j = A(c_j) \quad (4)$$

$$\text{chat}_j = (1 - \text{Theta}(c_j, T)) \cdot \text{Theta}(a_j, T_a) + (1 - \text{Theta}(a_j, T_a)) \cdot c_j \quad (5)$$

where $\mathbf{x}$ is the vector of all samples of $x(t)$, $\mathbf{c}_j$ is the vector of wavelet coefficients at scale j extracted using the operator S_j , a_j is the artefactness of $\mathbf{c}_j$ and $\text{Theta}(s, T)$ is the vectorial Heaviside function with input vector s and threshold T . We have used a hard threshold because we want to leave the artefact-free part of the signal unmodified. The artefact reduced signal $\hat{x}$ is thus obtained by fixing 2 thresholds: T_a for the artefactness and T_{c_j} for the wavelet coefficients. In the following, we have fixed these thresholds to $T_a = 0.4$ and $T_{c_j} = 1.5 \text{ Sigm}ac_j$. The artefact reduced signal is obtained with:

$$\hat{x} = W^{-1}(\text{chat}) \quad (6)$$

DPW Qualities All features are extracted using a rectangular sliding window of 30 s with 50% overlap. Normalization of the features is carried out and outlined in table 4.

Rhythmicity The pulse wave signal $DPW(t)$ displays fluctuations both in the frequency and amplitude domains. The fluctuations in the frequency domain are linked with known phenomena originating from the neuro-cardiovascular close-loop architecture with exogenous inputs such as the voluntary respiration or emotions. The variability of the pulse wave maximum peak location is *linked* to the Heart Rate Variability (HRV) which is defined as the variability of the peak electrocardiogram (ECG) R-wave time position (We say linked because the pulse wave as measured at the radial artery has been filtered from its original source in the left ventricle and contain phase distortions). The maximum of the pulse wave indeed corresponds to the maximum left ventricle contraction. The intervals signal of the pulse wave peak location is denoted PP similarly to the RR extracted from an ECG. The pulse wave maxima $Pare$ extracted using a maxima detection (hill climbing). The Peak-to-Peak intervals PP are then computed and outliers (intervals outside the range $[0.4, 2]$ s) are removed.

The classic measures of *PP* fluctuations are defined as: 1) the average pulse rate *Rm*, 2) the variance of the pulse rate *Rv*, 3) the Normalized Low Frequency Power (*LF*: frequency range 0.04 Hz to 0.15 Hz), 4) the Normalized High Frequency Power (*HF*: frequency range 0.15 Hz to 0.4 Hz).
 5 These indices indicate how the two-component autonomic nervous system, i.e. the sympathetic and the para-sympathetic systems, influences the fluctuations of the *PP* rhythm.

The fundamental properties of a rhythmic signal are displayed in its frequency spectrum as analyzed using a Fourier transform. The pulse wave
 10 contains a rich spectrum which is essentially related to the different functions of the cardiovascular and respiratory systems. Therefore two band-pass filters are applied to extract these 2 components prior to the spectral analysis. A Butterworth first order filters in the 2 frequency bands are used: 1) for the heart related subsignal *HPW(t)* in [0.6,2]Hz, and 2) for
 15 the respiratory subsignal *BPW(t)* in [0.1,0.4]Hz.

The number of harmonics Nb^H of the pulse wave, their amplitude $A_{H,k}$, location $f_{n,k}$ and bandwidth D_k^H , $k = 1, \dots, Nb^H$, are 4 main sets of features to characterize the rhythmicity. Due to the short duration of the signals, a parametric model of the signal is used to extract its power spectrum
 20 density. A Yule-Walker estimation is used with an Auto-Regressive model of order 12. The total bandwidth ($BW = D_0^H$) of the pulse wave is also computed. The bandwidth $\Delta_{H,k}$ of a signal x , centered around the frequency $f_{n,k}$, is computed as follows:

$$D_k^H = \text{Sqrt}(\text{Integral on } \Omega [P_{t_{\text{cha}}}(w) (w - 2\pi f_k^H)^2 dw]) \quad (7)$$

25 where Ω is the bandwidth of interest (in this case $\Omega = Fs/2$) and $P_{t_{\text{cha}}}(w)$ is an estimation of the energy-normalized power spectral density of the artefact reduced signal $\hat{x}(t)$: i.e.

$$P_{t_{\text{cha}}}(w) = P_{\hat{x}}(w) / \text{Integral on } \Omega [P_{\hat{x}}(w) dw] \quad (8)$$

Stability The concept of stability comes from the fact that both the *PP* and pulse wave amplitude naturally fluctuates in a multi-scale or/and chaotic way. Some long-term HRV studies have established the complexity of the heart rhythm and the influences of many physiological factors on the amplitude of the pulse wave across the arterio-venous tree. Stability is usually quantified using entropies or related indices. A Spectral Entropies and Lempel-Ziv Complexity is used in the present embodiment.

Frequency Domain Stability The Normalized Enhanced Spectral Entropy (ESE) is defined as:

$$ESE = - \text{Integral on } \Omega [P_{t_{xha}}(w) \log(P_{t_{xha}}(w)) dw] / \Omega \quad (9)$$

The ESE equation (9) resemble the classic Shannon entropy formula and is a measure of disorder of a signal in the frequency domain. Typically, narrow band signals will have a small entropy as compared to broadband signals.

Time Domain Stability Another way to quantify the Stability is by using the Lempel-Ziv Complexity (LZ) to a symbolized *PP* series. The easiest way to get a symbol out of a continuous value is to quantize it. In the present embodiment a standard quantization method based on 5 bits to obtain an integer value is used as a symbol for the LZ computation. The reason for using the LZ for pulse wave classification is that the pulse wave exhibits pseudo-periodic behaviour in certain Typologies and also when manifesting some disorder for which the LZ measure is very well adapted.

Amplitude Domain Stability Stability in the amplitude domain is characterized in first approximation by a Undulation Level (UL). The pulse wave is indeed modulated in amplitude due to various factors such as respiration, the autonomous nervous system or heart pacemaker dysrhythmias. In TTM language, these amplitude modulations are mainly the reflections of *Lung* or *Tripa* humors, as opposed to *Beken* which is more stable. The UL is also well adapted to measure the depth of modulation during Respiratory Sinus Arrhythmia (RSA), and thus the influences of the respiration on the pulse wave amplitude fluctuations. The concept of

Undulation Level used in this context is borrowed from the domain of telecommunication where UL is defined from the following equation:

$$x(t) = KU + UL \cos(\omega_{AM} t) \cos(\omega_{FM} t) + n(t) \quad (10)$$

$$= E_x(t) C(t) + n(t) \quad (11)$$

- 5 where $\omega_{AM, FM}$ is the angular frequency of the (Amplitude, Frequency) modulated part of $x(t)$ and $n(t)$ is some zero mean noise with $E[n(t)E_x(t)C(t)] = 0$, $E[\cdot]$ being the mathematical expectation. UL varies between 0 and 1.

- First Step:** In order to estimate UL from $x(t)$, it is necessary to first extract its
 10 envelope. In the present embodiment a combination of a Hilbert transform, followed by an Empirical Mode Decomposition (EMD) of the modulus of the Hilbert transform, is used. The reason for doing so is that the envelope extracted using the Hilbert transform can be quite noisy. On the other hand, using EMD only for extracting the envelope leads to some problems
 15 when there are undesired local extrema in the data, but has interesting detrending and denoising properties. Thus combining the two methods result in a more robust way for extracting the envelope and the estimation of UL . Moreover, the envelope dynamics also contains very interesting features that can be measured using spectral-based indices. The estimated
 20 envelope $\hat{E}x(t)$ extracted from $x(t)$ is thus computed as follow

$$\hat{E}x(t) = \text{EMD}[\text{abs}(\text{Hilbert}(x(t)))] \quad (12)$$

where Hilbert is the Hilbert transform operator and EMD is the denoising and detrending EMD operation. In order to avoid the complexity of the Hilbert transform, we can instead use a wavelet transform.

- 25 **Second Step:** The second step involved in determining an estimate of UL is performed in two phases. First a good approximation of UL is assumed by the following formulae:

$$UL_{\text{hat}}\sigma = \sigma_{\text{Ehat}} / \sigma_x \quad (13)$$

Second, by estimating the numerator and denominator of (13) and using (11) we find:

$$\sigma_{\text{Ehat}} = K^2 UL_{\text{hat}}^2 \quad (14)$$

$$5 \quad \sigma_x = (K^2/2) (1 + UL_{\text{hat}}^2/2) \quad (15)$$

Rearranging the terms from (14) and (15) into (13), we finally obtain an estimate of UL :

$$UL_{\text{hat}} = \sqrt{1/(UL_{\text{hat}}^2\sigma - 1/2)} \quad (16)$$

Features Selection We have nine features which are summarized in Table 5 which enable a quantitative D2T correspondence when combined with Table 2 (Fig. 11) and Table 3.

Rhythmicity	<i>(LF, HF, Rv, Rm)</i>	<i>BF</i>	<i>BW</i>
Stability	<i>EUL</i>	<i>BW</i>	<i>ESE</i>

Table 5: Summary of our DPW Qualities and Features

As explained the pulse wave is sensed and recorded on both wrists of the subject. The fact that left and right wrist shows different TTP characteristics is also found true in our DPW features. Thus, three sets of features are identified: 1) on the left hand, 2) on the right hand and 3) on the difference between the left and the right hand.

Automatic feature selection is performed which will be described hereafter. Feature selection is a necessary step in order to reduce the input space dimension of the classifier and improve its robustness and generalisation.

Step 1: Features Selection using mRMR There are a number of feature selection procedures which can be classified as: 1) Classifier-Independents algorithm, and 2) Classifier-Dependent algorithms. In the first category

there is for instance correlation based methods, principal and independent component analysis; while in the second, also called wrappers and embedded methods, support vector machines, naive-Bayes, decision trees and neural networks can be found. The second category is usually more
 5 time and resource consuming than the first. The first category is data-driven, fast and essentially based around a notion of separation of categories and thus a distance. The most common distance is the correlation but is known to have weaknesses especially when the data sets are nonlinearly related. A very attractive notion of distance or separation
 10 or dissimilarity is the mutual information. A method developed by Peng *et al.* called mRMR (minimum Redundancy Maximum Relevance Feature Selection) has been chosen and applied in this embodiment of the present invention. The mRMR method requires that the feature values be converted to symbols. In order to do this, the features are quantized using a standard
 15 quantization method on 5 bits. Each quantized level is then assigned an integer value, which together with the classes are the input to mRMR.

The result of mRMR using this method is summarized in Table 6. In this Table, the features have to be read from left to right and are in order of decreasing minimum redundancy. Progressively grouped features from left
 20 to right also have decreasing minimum redundancy.

	mRMR Selected Features
Left Hand	EUL-hZrr-Rm-HF
Right Hand	Rm-BWh-BF-EUL
Left - Right Hand	Rv-ESEh-EUL-Rm

Table 6: mRMR Feature Selection

The results of the mRMR Feature Selection show that each wrist contains its own information about the Typology: i.e. the 2 left most feature sets have (EUL, Lzrr) and (Rm,BWh) have no common features. This
 25 suggests that our choice of features were *a posteriori* appropriate for Typology discrimination. EUL and LZrr, Rm and BWh, are retained for further use. Feature Statistics from Table 6 are illustrated for a number of subjects in Fig. 6 to 8.

Features SurrogatesIn order to improve the robustness of the classification, surrogates of the features are used. By using Schreiber method as a first step, we can further improve the surrogate by carrying out a second step which makes the surrogate probability density function (pdf) invariant also.

- 5 This second step guarantees that the surrogates' pdfs are preserved. This surrogate method may be further used in to test the performance of the classifier by using Monte Carlo simulations of the classifier.

- Step 2: Features Selection using Principal Component Analysis**In order to further ease the work of the classifier, performed a Principal Component Analysis in State Space (PCA-SS) to the feature retained in Step 1. The parameters for the nonlinear embedding are: dimension $m=4$ and lag $l=1$.
- 10

- The Figure 3(a) shows Feature Clusters after PCA-SS on the Left and Right hands and Figure 3(b) shows Left minus Right hand. These clusters have been obtained during a manual feature selection procedure as will be explained.
- 15

- The first four Principal Components noted as Space 1 to 4 in Fig 3, have been chosen for display. Figure 3(a), shows that left and right hand clusters are almost completely overlapping. We can further see from this Figure 3(a) that *Tripa* and *Beken* are nicely separable in Spaces 1 and 2, while *Lung* is overlapping the other 2 clusters. Referring to Figure 3(b), it can be seen that *Lung* is almost non-overlapping with the clusters *Tripa* and *Beken* which are themselves completely overlapped in all Spaces. These clusters provide a road to the solution of the classification as follows:
- 20

- first the Left minus Right PCA-SS components in any Spaces are used to separate *Lung* from *Tripa* and *Beken* (Spaces 1 and 2 have been chosen in this embodiment); and
- 25

second the Left hand PCA-SS components in Spaces 1 and 2 are used to delineate *Tripa* from *Beken*.

- Lower levels Spaces Clusters are more distinguishable than higher level ones which are more overlapping. It is thus advisable to use lower level Space components for feeding the classifier.
- 30

Classification of the three Typologies, The classifierAs explained each individual possesses a dominant Typology and sometimes manifest the other two. The classification of the Typology must thereby take this into account, which imposes a classifier with continuous output values rather than binary. Fuzzy classifiers are thus the most appropriate. Amongst the
 5 fuzzy classifiers, a special type of Artificial Neural Networks called Quantum Neural Networks (QNN) are preferred. These QNNs are a class of feedforward neural networks which can handle uncertain inputs and have a very flexible structure of hidden nonlinear layer in the form of a
 10 superimposition of sigmoidal functions with flexible amplitude, slope and shift. The hidden layer can focus or relax its *data representation* by concentrating or spreading around regions of certainties or uncertainties of the feature space more like a quantum wave function localize or spread out around certain or uncertain states bearing some resemblance to
 15 quantum systems and networks. The nonlinear hidden functions have a multi-sigmoidal shape which gives rise to a soft staircase shape. The hidden layer sigmoid functions are here referred to as Quantum Jumps.

The training algorithm of the QNN adapt both the linear input weights, the nonlinear output functions and all the parameters of the
 20 hidden layers. A gradient descend has been used. The stopping criteria for the training is based on a threshold on the normalized mean square error (NMSE). The initial conditions are chosen at random in the input space and the training is iterated on batch until the minimum training NMSE reaches the threshold. In this particular example, forty surrogate PCA-SS
 25 components are generated to train the QNN: i.e. the original feature set is artificially reproduced using the surrogate method as explained above. One hundred batch iteration are used to train the QNN on the surrogated data.

The trained network is then validated using additional independent surrogated data. These surrogates are then used to compute the Receiver
 30 Operating Curves of the QNN in a Monte Carlo simulation. The ROC curve indicates the performance of the classifier in terms of True Positives (Sensitivity) vs False Positives (1 - Specificity). A good classifier will have a

curve that raise quickly to one, while a poor classifier will have a curve that stays around the diagonal line.

The confusion matrix is also computed from these Monte Carlo simulations. The confusion matrix C of the QNN is given a

$$C = \begin{pmatrix} C_{1,1}^1, C_{2,1}^1, C_{1,1}^2, C_{2,1}^2 \end{pmatrix} \quad (20)$$

The diagonal entries $C_{1(2)}^{1(2)}$ are related to the percent of samples which are correctly classified in the respective Class **1(2)**. The off-diagonal entries in C have the following meaning: $C_{2(1)}^{1(2)}$ is the percentage of samples from Class **1(2)** which are classified as Class **2(1)**. Thus it is sought to maximize the diagonal elements, while minimizing the off diagonal elements, ideally **100%** and **0%** respectively.

Separation of Lung from Tripa and Beken As explained the Spaces **1** and **2** from the Left-Right hand PCA-SS components have been used. A QNN with three Quantum Jumps and **20** hidden units has been used. This QNN is called QNN First Pass: QNN^{FP} . The training gains are set as: $\alpha_L = 1$ for the linear layers and $\alpha_{NL} = 1$ for the nonlinear hidden layers. The hidden layers are unbiased sigmoid functions of saturating value **1** and middle slope of **1**. The output layer has the same characteristics. By assumption Class **1** is assigned to *Lung*, while Class **2** is assigned to the union of *Tripa* and *Beken*: (*Tripa* - *Beken*).

Manual Feature Selection In order to assess the mRMR feature selection, visual inspection of the data clusters is first carried out and a choice is made to use the following features: *Rm*, *Rv*, *BWh* and *LF*. The confusion matrix C^{FP} of the QNN^{FP} is given as:

$$C^{FP} = \begin{pmatrix} c_1^{FP,1}=90(2), c_2^{FP,1}=10(2), c_1^{FP,2}=25(2), c_2^{FP,2}=75(2), \end{pmatrix} \quad (21)$$

The diagonal entries in C^{FP} signifies that **90%±2%** of the samples are correctly classified in the *Lung* Class while and **75%±2%** are correctly classified in (*Tripa* - *Beken*). The off-diagonal entries in C^{FP} have the

following meaning: $C_2^{FP,1}$ is the percentage of samples from *Lung* which are miss classified as belonging to (*Tripa - Beken*), while $C_1^{FP,2}$ is just the opposite.

The ROC curves are shown in Figure 4(a) and (b). Figure 4(a) shown
 5 curves which result from manual feature selection, and figure 4(b) show curves which result from mRMR feature selection. The transparent colored area in the ROC curve are drawn as the average ROC plus/minus the standard deviation computed from the Monte Carlo simulation. It can see that the QNN^{FP} performs well under 10% False Positive for *Lung* and has
 10 difficulties increasing the True Positive. For (*Tripa - Beken*) the True Positives achieve more than 90% at a False Positive rate of less than 20%.

mRMR Feature Selection Using the mRMR feature selection as presented the following confusion matrix can be obtained:

$$C^{FP} = (C_1^{FP,1}=85(2), C_2^{FP,1}=15(2), C_1^{FP,2}=28(2), C_2^{FP,2}=72(2),) \quad (22)$$

15 Note that the feature clusters used in this mRMR are not those displayed in Figures 3(a) and (b) which are those used in the manual feature selection. The ROC curves are shown in Figure 4(b). The curves show a lower performance than with the manual feature selection, with still a similar performance as revealed by C^{FP} . Following the separation of Lung from
 20 Tripa and Beken, next the separation of Tripa and Beken is performed.

Separation of Tripa from Beken This QNN is called QNN Second Pass: QNN^{SP} . The training gains are set as: $\alpha_{L1} = 1$ for the linear layers and $\alpha_{NL} = 1$ for the nonlinear hidden layers. The hidden layers are unbiased sigmoid functions of saturating value 1 and middle slope of 1. The output
 25 layer has the same characteristics. By assumption Class 1 is assigned to *Tripa*, while Class 2 is assigned to *Beken*.

Manual Feature Selection The confusion matrix C^{SP} of the QNN^{SP} is given as:

$$C^{SP} = (C_1^{SP,1}=94(2), d^{P,1}=6(2), d^{P,2}=29(2), d^{P,2}=71(2),) \quad (23)$$

The diagonal entries in C^{SP} signifies that $94\% \pm 2\%$ of the samples are correctly classified in the *Tripa* Class while and $71\% \pm 2\%$ are correctly classified in *Beken*. The off-diagonal entries in C^{FP} have the following meaning: $C_2^{FP,1}$ is the percentage of samples from *Tripa* which are miss
 5 classified as belonging to *Beken*, while $C_1^{FP,2}$ is just the opposite.

The ROC curves are shown in Figure 5. Figure 5(a) shows the ROC curves for QNN^{SP} with manual feature selection, while figure 5(b) shows the ROC curves for QNN^{SP} with mRMR feature selection.. The ROC curve for *Beken* shows a good performance, while the one for *Tripa* shows a medium
 10 performance with 80% True Positives at the cost of 20% False Positives.

mRMR Feature Selection With the mRMR procedure, we obtain the following confusion matrix:

$$C^D = (C_1^{SP,1}=90(2), C_2^{SP,1}=10(2), C_1^{SP,2}=14(2), C_2^{SP,2}=86(2),) \quad (24)$$

Note that the feature clusters used in this mRMR are not those displayed in
 15 Figures 3(a) and (b) which are those used in the manual feature selection. The ROC curves are shown in Figure 5(b). Both ROC curves for *Beken* and *Tripa* shows good performance with more than 80% True Positives at the cost of less than 10% False Positives. This is due to a better feature configuration as compared to the manually selected features.

20 Fig 9 provides a flow chart which summaries the steps involved in a method according to an embodiment of the present invention. The first step involves taking measurements of the patient's pulse using a PPG sensor so as to obtain a digital pulse wave (140).

A digital pulse wave is then generated using analog to digital
 25 converter circuits and filtering (141). Next, features are extracted from the DPW and include the mean value of interval PP(Rm), normalised variance of PP(Rv), normalised enhanced undulation level of a heat pulse wave (EUL), normalised enhanced spectral entropy of a heat pulse wave (ESEh), Lempel-Ziv complexity of the persons heart pulse wave PW (LZrr) and normalised

breathing frequency (BF). HeartRate Variability indices in the frequency domain (LF and HF), the variance of the PPintervals, the breathing frequency (142).

- 5 Next a selection of the features which are to be used to determine the Typology of the person, i.e. the Tibetan States, is performed (143). Selection of the parameters is based on either the manual selection or mRMR procedure as explained above. Following the feature selection, Classic States of heart, breathing and relaxing conditions are also computed.

- 10 Following the selection of the features, principal component analysis is performed on the selected features so as to better condition the input space for further classification (144).

Next clusters which result from the principal component analysis are classified into wind (lung), bile (Tripa) and phlegm (Beken) which are the three Tibetan States(145).

- 15 Figs. 10a,b, and c each illustrate a flow diagram of the steps which involved in a method according to an embodiment of the present invention.

- 20 A photoplethysmograph (PPG) sensor 150 which is configured to be worn on the wrist of a patient is first secured to the wrist of the patient. Note that the PPG sensor can take any other form than the one illustrated in Fig. 10 that is suitable for measuring the pulse at the wrist, hands, fingers or ears of the person. For example, the PPG sensor can take the form of a behind-the-ear, in-the-ear, etc., hearing aid types. The photoplethysmograph (PPG) sensor 150 senses a pulse (161) of the patient and outputs a PPG signal which contains information regarding the pulse of the subject (151).
- 25

Additionally, the movement of the subject is measured (152) using one or more accelerometers (not shown) which are integral to the photoplethysmograph (PPG) sensor (150). Preferably the movement of

the subject is continuously measured. The measured movement is compared to a threshold movement value (T_a) (158). The PPG signals output from the photoplethysmograph (PPG) sensor 150 are only passed to the next stage in the process if the measured movement is less than the threshold movement value (T_a). The measured movement of the person may also be passed (159) to be output on a holistic display (160).

An indicator of the movement of the subject could be displayed on the display unit (160). When the movement of the subject is above the threshold (T_a), it is understood that the Classic States cannot be computed and thus displayed.

If the measured movement is less than the threshold movement value (T_a) then the PPG signals output from the photoplethysmograph (PPG) sensor 150 are processed to determine their quality. A quality index value (QI) (153) which is representative of the quality of the PPG signals is determined; and the quality index value (QI) (153). The quality index value (QI) is compared to a threshold quality index value (T_{qi}) (154). It will be understood that the quality index value could be displayed on a holistic display 160.

The PPG signals output from the photoplethysmograph (PPG) sensor 150 are passed for further processing only if the quality index value (QI) is greater than the threshold quality index value (T_{qi}) (155). Further processing of the PPG signals will include generating a digital pulse waveform which is representative of the pulse of the patient; determining one or more features from the digital pulse waveform (the one or more features may include features such as pulse wave envelope, heart PP intervals, heart rate, heart rate variability indices in the frequency domain, breathing frequency and spectral entropy of the PP intervals). It will be understood that any of these parameters could be displayed on the holistic display 160. Further steps include using the one or more features to determine the heart condition, breathing condition and relaxing condition of the patient and displaying these values which are representative of these conditions on the holistic display.

It will be understood that the further processing of the PPG signals may be carried out on an operating system and that the method may include the step of streaming PPG signals output from the photoplethysmograph (PPG) sensor 150 to the operating system so that further processing can be performed. Other measurements such as breathing and heart features derived from the PPG signals may also be streamed to the operating system. Breathing and heart features may also be obtained from the PPG signals during the further processing steps (157).

The steps involved in the method illustrated in Fig 10b are similar to those of Fig 10a and like steps are awarded the same reference numbers. However, instead of using the one or more features to determine the heart condition, breathing condition and relaxing condition of the patient, the one or more features are used to determine the ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person possesses, and displaying the ratios on a holistic display 172. The holistic display can comprise a mechanical-based mechanism including hands, discs or the like, or an electronic display.

Also in the method illustrated in Fig 10b the processing of the PPG signals to, generate a digital pulse waveform which is representative of the pulse of the patient, determining one or more features from the digital pulse waveform (the one or more parameters may include features such as pulse wave envelope, heart PP intervals, heart rate, heart rate variability indices in the frequency domain and spectral entropy of the PP) are carried out on an operating system 170 which includes a holistic display 172 which is located remotely. The PPG signals streamed 171 to the operating system 170; the measured movement is also streamed to the operating system along with breathing and heart features which have been determined from the PPG signals. It will be understood that any of these features could be displayed on the holistic display 172 of the operating system 170. The operating system is operable to determine the ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person possesses and to display the ratio on the holistic display 172.

Thus the method illustrated in Fig 10a is used when it is desired to determine and display the heart condition, breathing condition and relaxing condition of the body and mind of a patient, whereas the method illustrate in Fig 10b is used when it is desired to determine and display
5 theratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person possesses.

The method illustrated in Fig 10c is used to monitor a patient while sleeping. In particular the method is used to determine and display theratio of wind (lung), bile (Tripa) and phlegm (Beken) typology that the person
10 possesses while sleeping and also to determine and display theheart condition, breathing condition and relaxing condition of the body and mind of a patient.

In this particular example the movement of the patient is still measured using accelerometers, as in the method of Fig 10a, however the
15 measured movement is not compared to a threshold movement value. Furthermore neither is a quality index, representing the quality of the PPS signals, determined and the PPG signals output from thephotoplethysmograph (PPG) sensor 150 are passed for further processing regardless of their quality. However, it will be understood that a
20 threshold movement value and threshold quality index could be used in this method in a similar fashion to the manner in which they are used in the methods of Fig 10a and Fig 10 b.

The method illustrated in Fig 10c has many of the same features as the methods illustrated in Figs. 10a and 10b and like features are awarded the
25 same reference numbers.

In the example illustrated in Fig 10c the PPG signals output from thephotoplethysmograph (PPG) sensor 150 are streamed (181) to an operating system 180 for further processing. The operating system 180 is configured touse the PPG signal to generate a digital pulse waveform
30 which is representative of the pulse of the patient; determine one or more features from the digital pulse waveform (the one or more features may

include parameters such as pulse wave envelope, heart PP intervals, heart rate, heart rate variability indices in the frequency domain and spectral entropy of the PP); and to determine the heart condition, breathing condition and relaxing condition of the patient, and the ratio of wind (lung), bile (Tripa) and phlegm (Beken) typology that the person possesses, using the one or more features. The operating system 180 is further used to display values which are representative of the heart condition, breathing condition and relaxing condition of the patient and to display the ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typology that the person possesses, on a holistic display 182.

It will be understood that any of the one or more features could be displayed on the holistic display 182. Thus the method illustrated in Fig 10c is employed to monitor the patient when the patient is sleeping, and heart condition, breathing condition, relaxing condition and the Typology of the patient is determined and displayed using this method.

Various modifications and variations to the described embodiments of the invention will be apparent to those skilled in the art without departing from the scope of the invention as defined in the appended claims. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiment.

Claims

1. A method for determining the state of a person, comprising the steps of:
 - sensing a pulse of the person using a photoplethysmograph (PPG) sensor;
 - 5 generating a digital pulse waveform which represents the sensed pulse;
 - determining one or more features from the digital pulse waveform; and
 - using the one or more features to determine the state of the
 - 10 person possesses.
2. The method according to claim 1 wherein the state of the person may comprise at least one of, the heart condition, breathing condition and/or relaxing condition of the person.
3. The method according to claim 1 or 2, wherein
- 15 the state of the person comprises a Tibetan state of the person and the Tibetan state of the person comprises a ratio of wind (lung), bile (Tripa) and phlegm (Beken) Typologies that the person possesses.
4. The method according to any one of the preceding claims, wherein the one or more features comprise at least one of, heart rate
- 20 variability, spectral entropy and/or undulations level indices.
5. The method according to claims 3 or 4, comprising the step of:
 - sensing the pulse at the wrist, hands, fingers of the person's left hand or left ear of the person, and sensing the pulse of the person at wrist, hands, fingers of the person's right hand or right ear of the person;
 - 25 generating a first and second digital pulse waveforms each of which represents the pulse sensed at the wrist, hands, fingers of the person

left and right hand respectively or left or right ear of the person, respectively; and

determining one or more features of each of the first and second digital pulse waveforms; using the one or more features to determine the
5 ratio of wind, bile and phlegm Typology that the person possesses.

6. The method according to claims 3 or 4, comprising the step of:
sensing the pulse at one of the left and right wrist, hands, fingers
or ear of the person; generating a corresponding DPW;
determining one or more features of the corresponding DPW;

10 and

using the one or more features in combination with a set of reference features extracted from offline population average to determine the ratio of wind, bile and phlegm Typology.

7. The method according to any one of the preceding claims,
15 further comprising the step of measuring the movement of the person.

8. The method according to claim 7,
comprising the step of comparing the measured movement of the person to a threshold level of movement; and determining one or more parameters of the digital pulse waveform only if the measured movement
20 of the person is below the threshold level of movement.

9. The method according to any one of the preceding claims, wherein the digital pulse waveform is generated using a PPG signal which are output from the photoplethysmograph (PPG) sensor when the photoplethysmograph (PPG) sensor is sensing the pulse of the person; and
25 wherein the method further comprises determining a quality index value which is representative of the quality of the PPG signal, and comparing the quality index value to a threshold quality index value; and wherein the step of determining the one or more features of the digital pulse waveform performed only if determining a quality index value is
30 greater than the threshold quality index value.

10. The method according to any one of claims 3 to 9,
further comprising the step of selecting a subgroup of features from the
one or more features from the determined one or more features of the
digital pulse waveform; and using the selecting subgroup of features, to
5 determine the ratio of wind, bile and phlegm Typologies that the person
possesses.

11. The method according to any one of the preceding claims,
further comprising the step of:

performing principal component analysis on the one or more
10 features to delineate the different state of a person; and

performing principal component analysis on the one or more
features may be carried out to generate clusters which are representative
of the wind (lung), bile (Tripa) and phlegm (Beken) Typology of the person.

12. The method according to claim 11,
15 further comprising the step of identifying which cluster corresponds to
wind (lung), bile (Tripa) and phlegman (Beken) Typology respectively.

13. The method according to claim 11,
further comprising the step of classifying the clusters which have been
computed during principal component analysis and which are
20 representative of the wind (lung), bile (Tripa) and phlegm (Beken) Typology
respectively, from each other.

14. The method according to claim 13,
wherein the classifier is of Neural Network class or similar.

15. The method according to claim 13,
25 wherein supervised training of the classifier is used with a Tibetan Doctor
previously labelled Typologies.

16. A method according to any one of claims 3 to 15,
wherein the steps of the method are performed while the person is
sleeping to determine a first ratio of the wind (lung), bile (Tripa) and

- phlegm (Beken) Typology of a person, and
 wherein the steps of the method are performed while the person is
 awaketo determine a second ratio of the wind (lung), bile (Tripa) and
 phlegm (Beken) Typology of a person, and
 5 wherein the method further comprises the step of detecting changes
 between the first and second determined ratios.

17. The method according to any one of the preceding claims,
 wherein the photoplethysmograph (PPG) sensor is configured to be worn
 about the wrist, hands, fingers or ears of a person, and the method
 10 comprises securing the photoplethysmograph (PPG) around the wrist,
 hands, fingers or ears of a person such that the photoplethysmograph
 (PPG) is arranged so sense pulse at the wrist, hands, fingers or ears of the
 person.

18. A system for determining the state of a person, comprising:
 15 a photoplethysmograph (PPG) sensor which is configured to
 generate a digital pulse waveform which represents a sensed pulse of
 the person;
 a means for determining one or more features of the digital
 pulse waveform; and
 20 a means for determining the state of the person from the one or
 more features of the digital pulse waveform.

19. The system according to claim 18,
 wherein the means for determining the state of the person comprises at
 least one of; a means for determining the heart condition, breathing
 25 condition and/or relaxing condition of the person from the one or more
 features of the digital pulse waveform; and/or a means for determining
 the ratio of wind, bile and phlegm typologies that the person possesses
 from the one or more features of the digital pulse waveform.

20. The system according to claim 18 or 19,
 30 further comprising a streaming unit which allows the system to

communicate remotely and wirelessly to a processor for further data analysis and display.

21. The system according to any one of claims 18 to 20,
further comprising a digital display unit and which is capable of showing
5 the state of the person in a holistic way by means of colors, images or else,
animated or not.

22. The system according to any one of claims 18 to 21,
further comprising an analog display unit which is capable of showing the
state of the person in a holistic way by means of mechanical, optical or
10 electronic means.

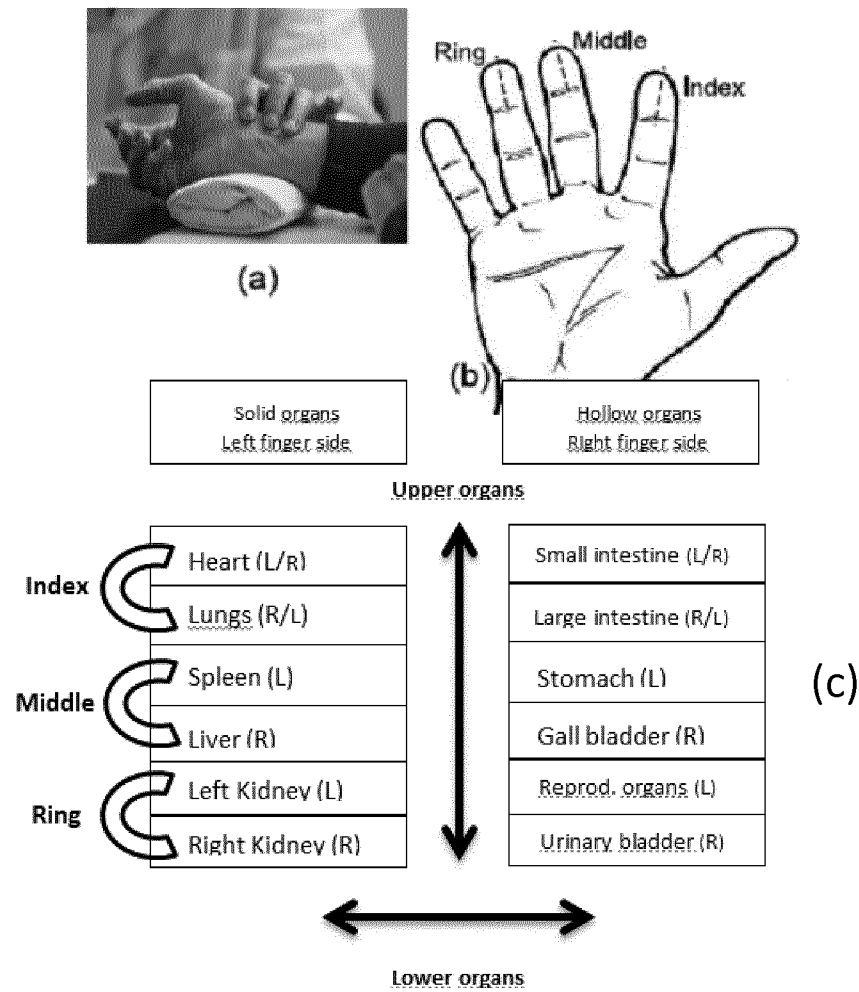


Fig. 1

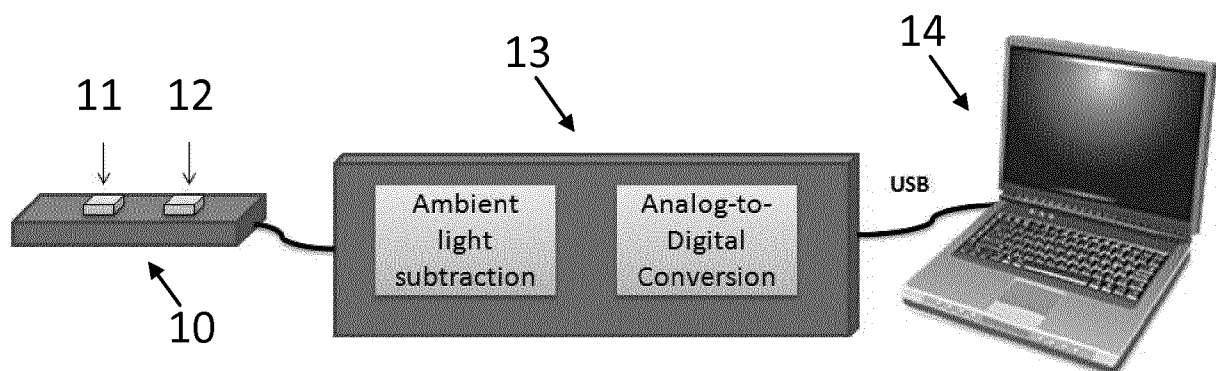


Fig. 2

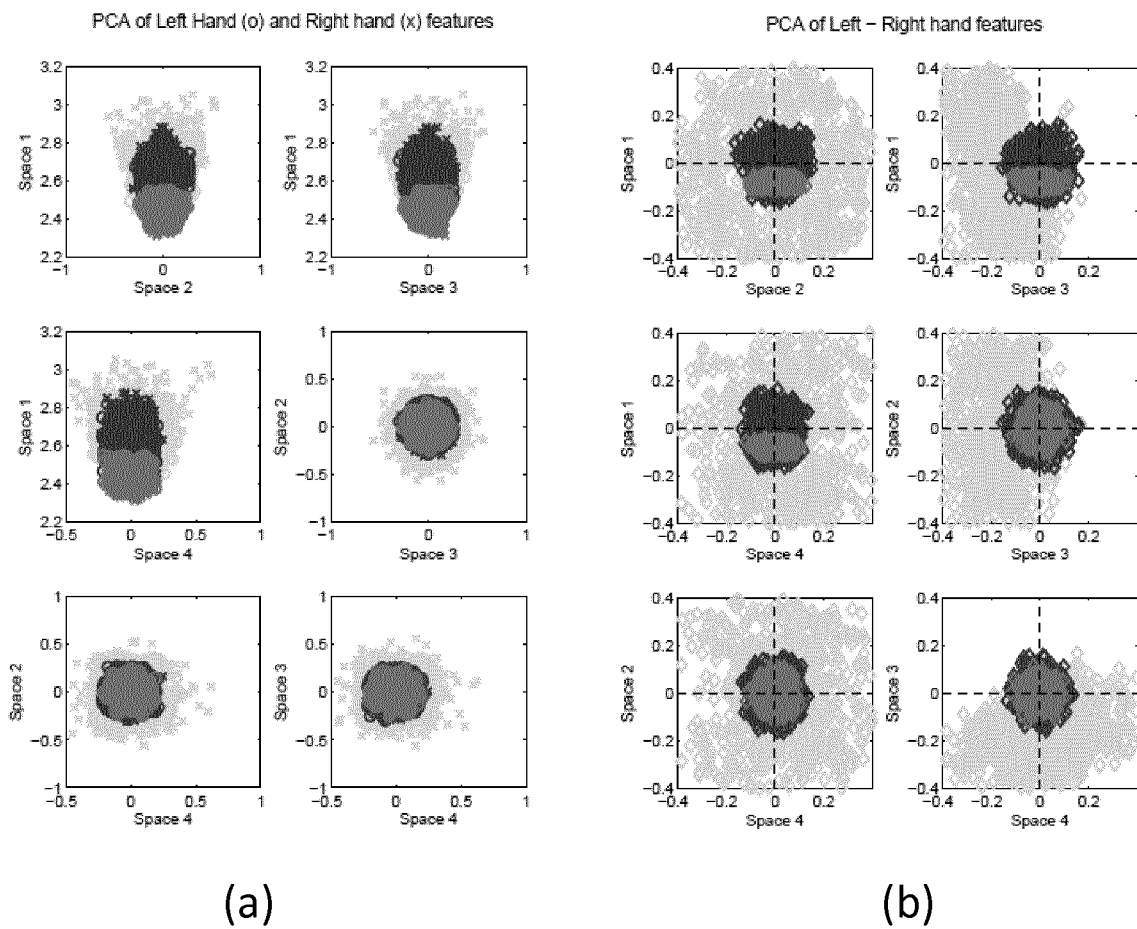


Fig. 3

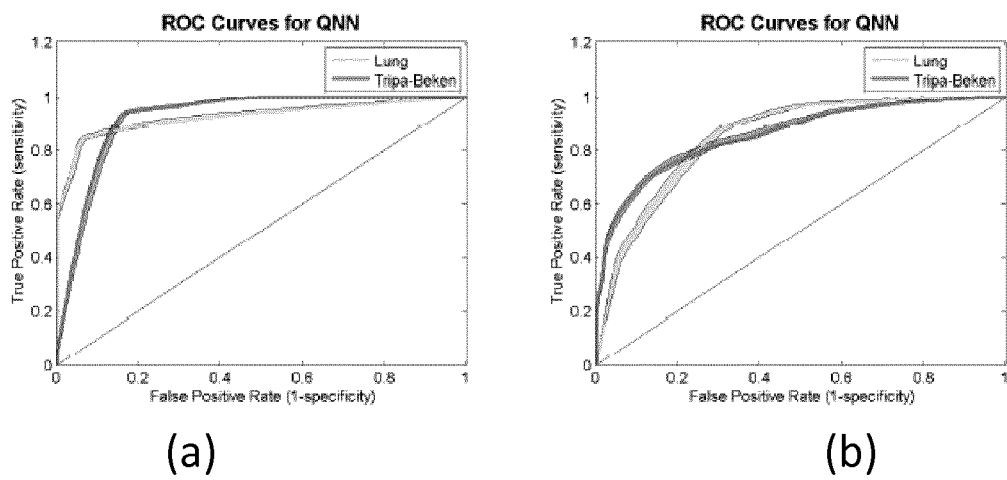


Fig. 4

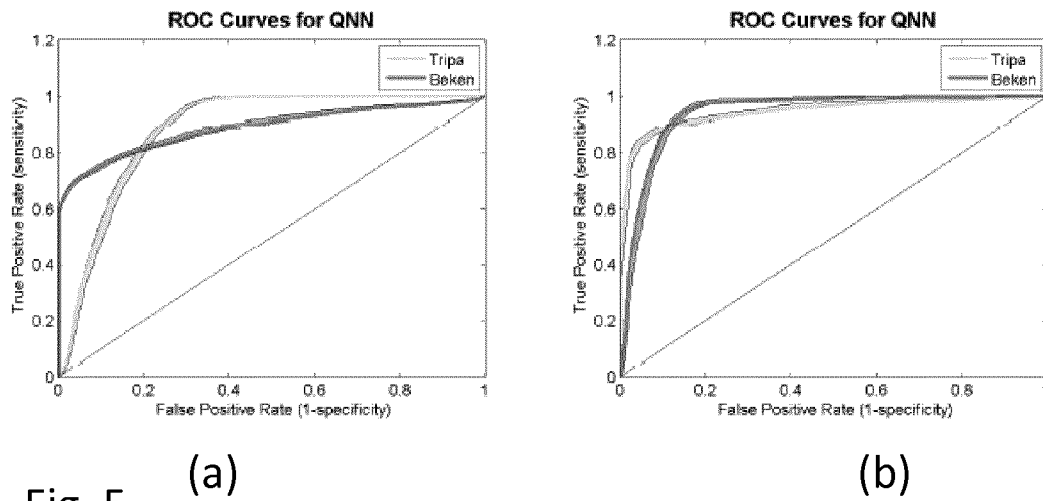


Fig. 5

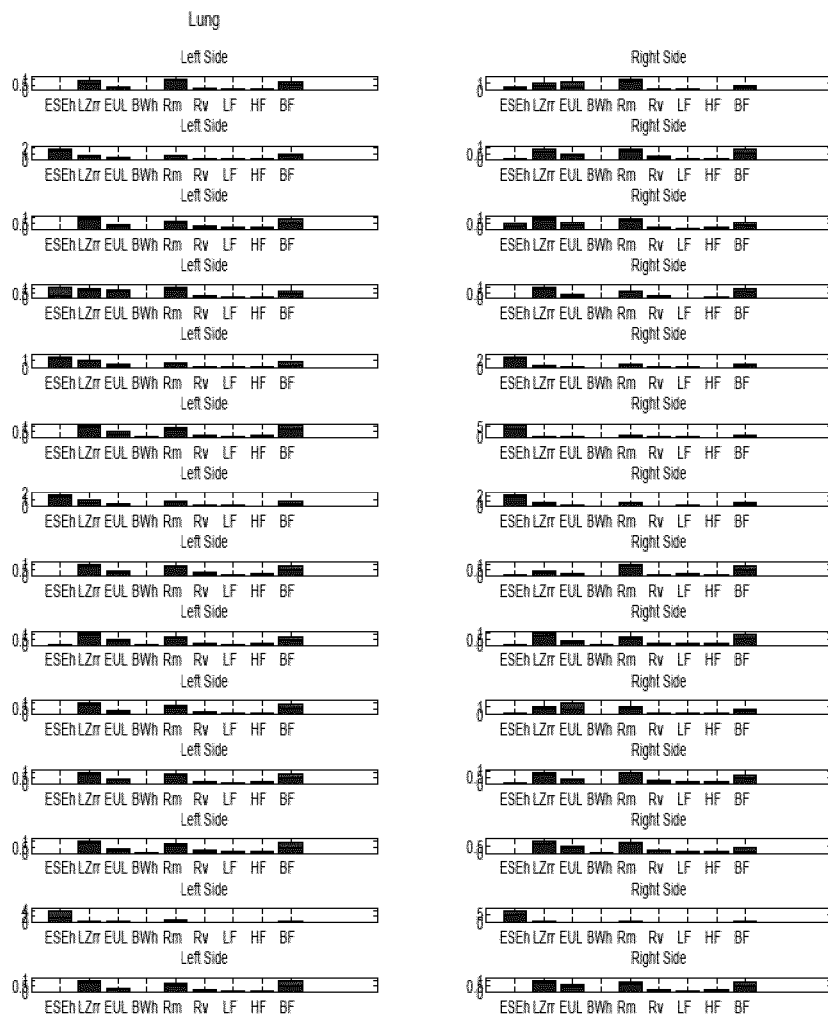


Fig. 6

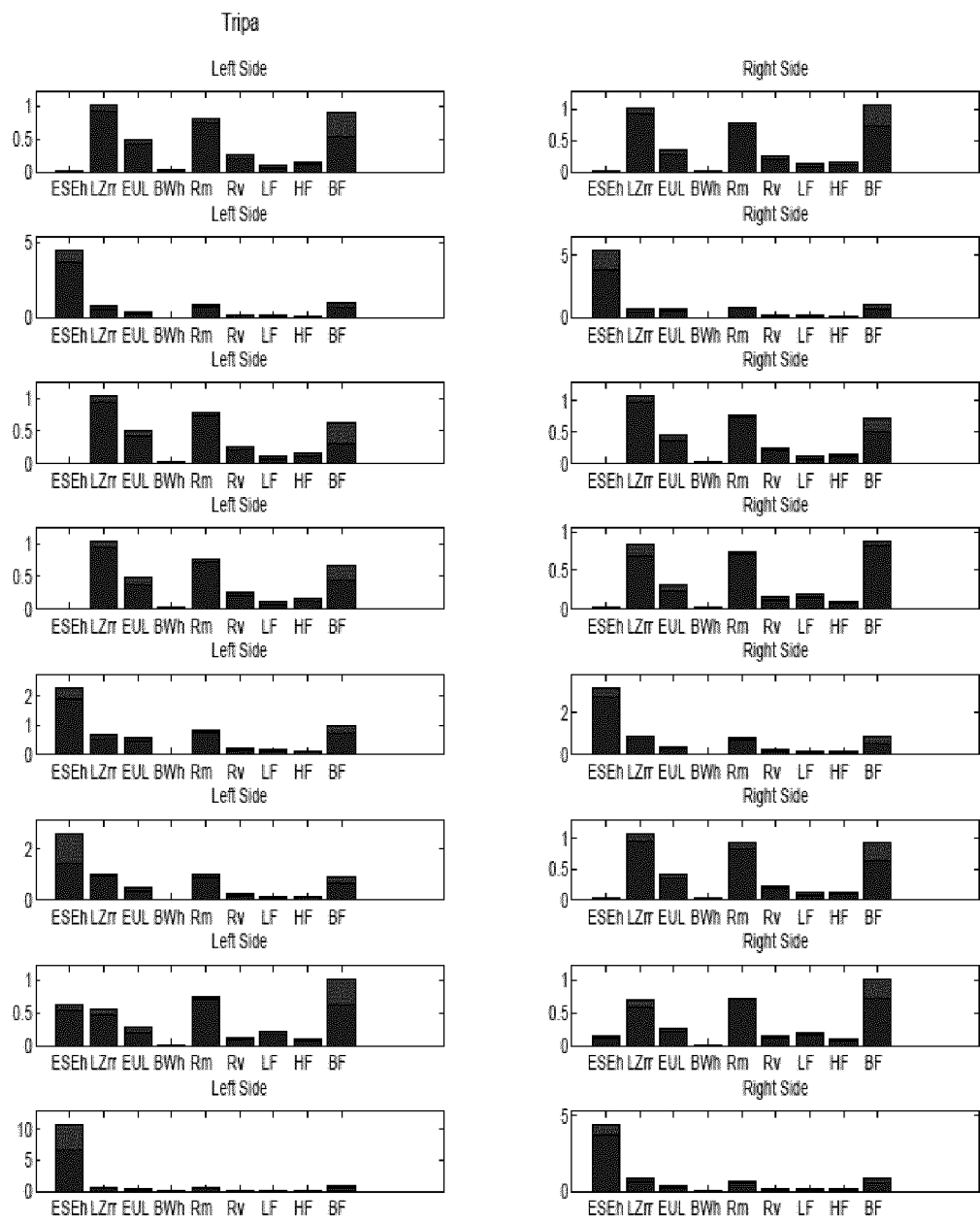


Fig. 7

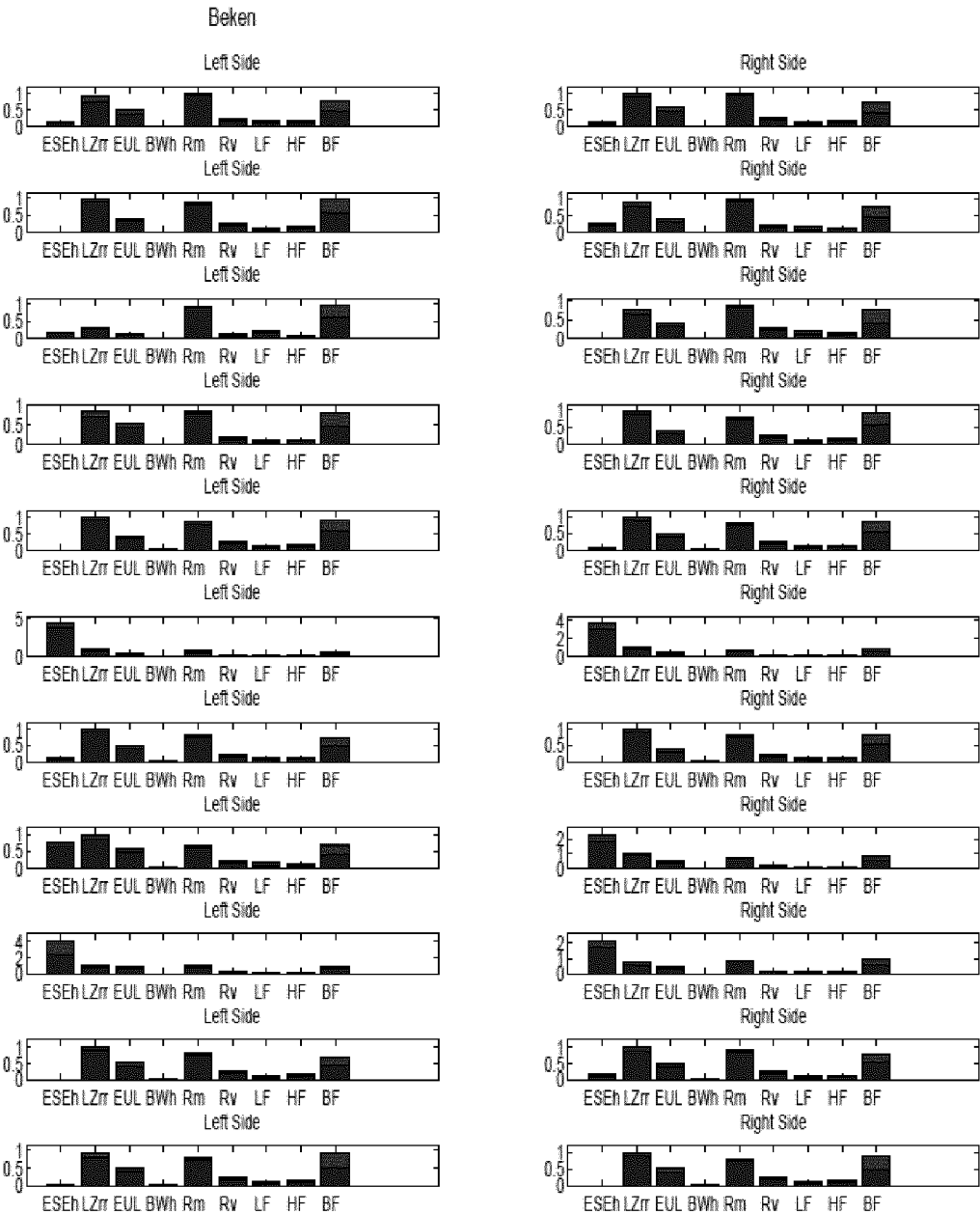


Fig. 8

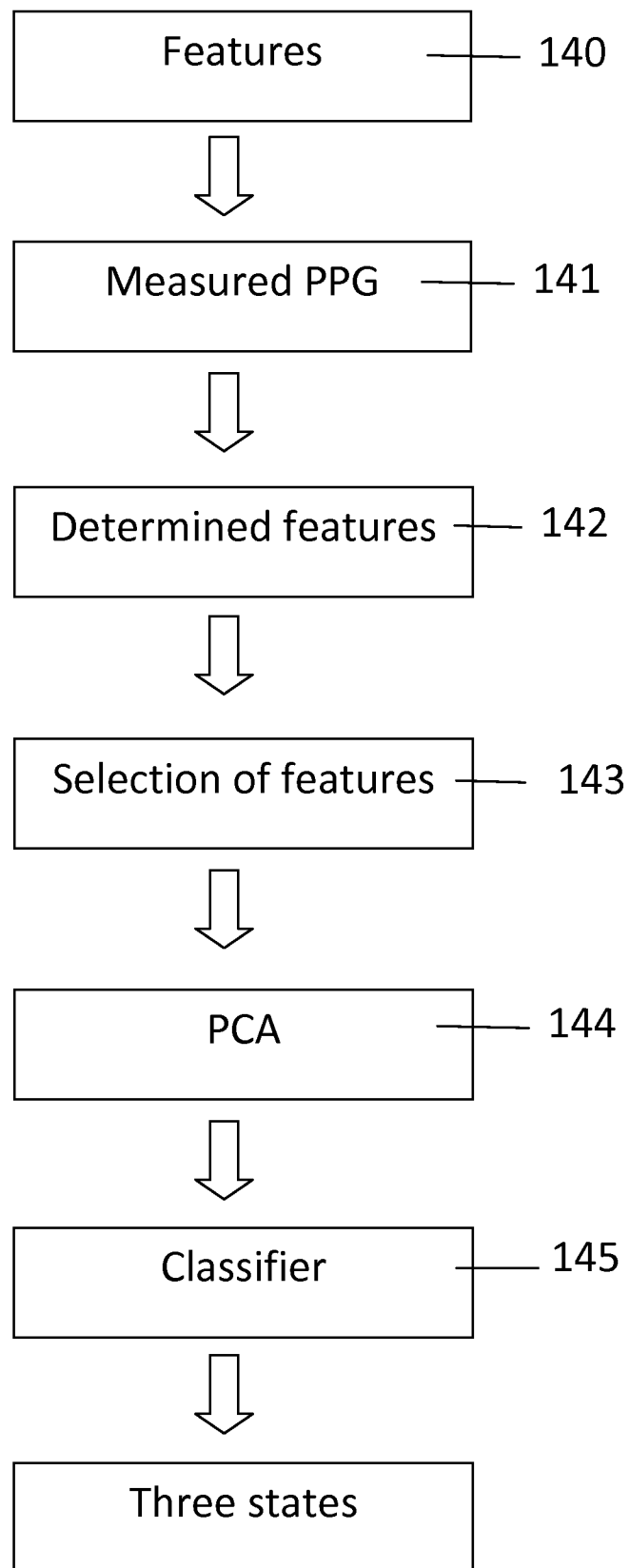


Fig. 9

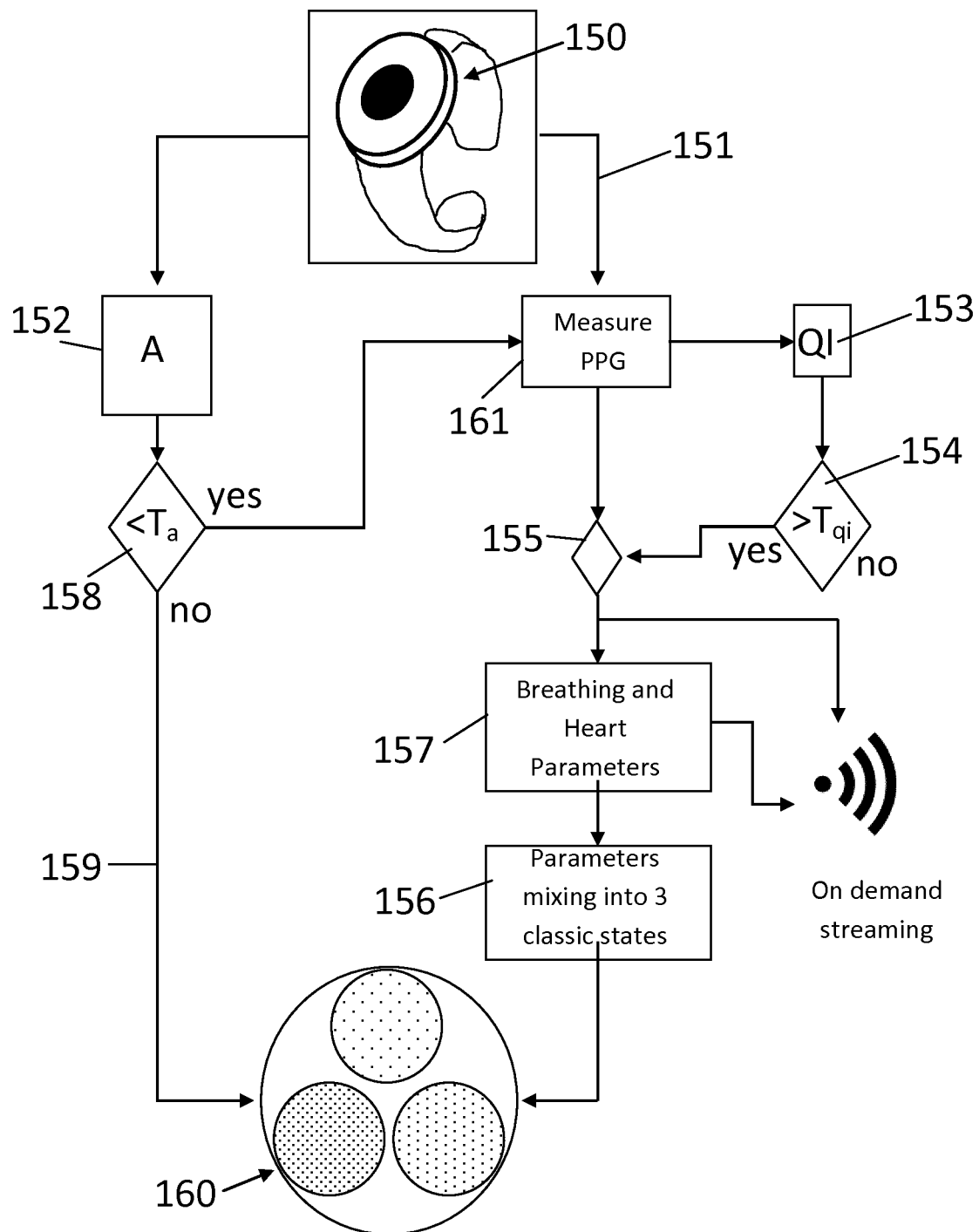


Fig. 10 a

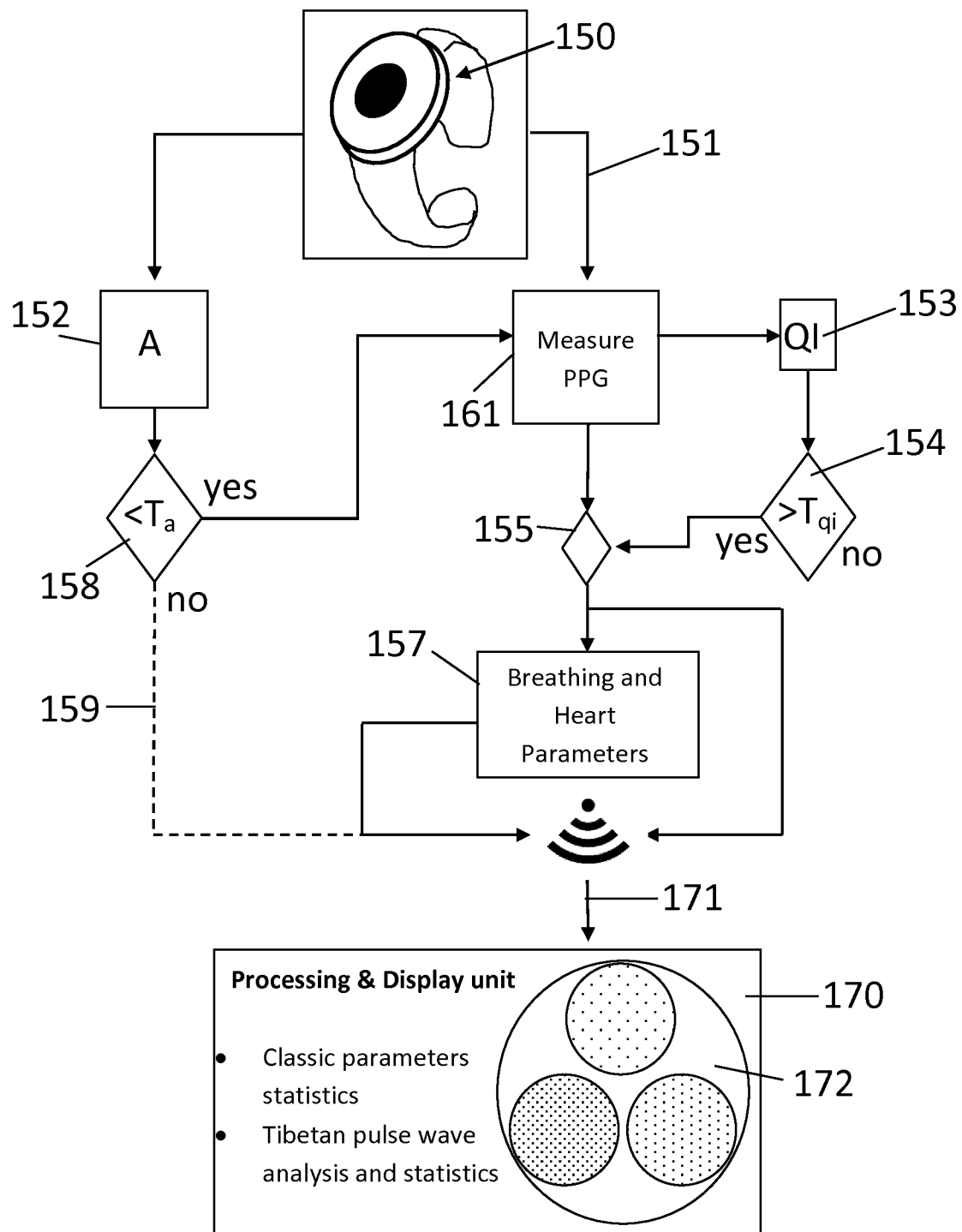


Fig. 10b

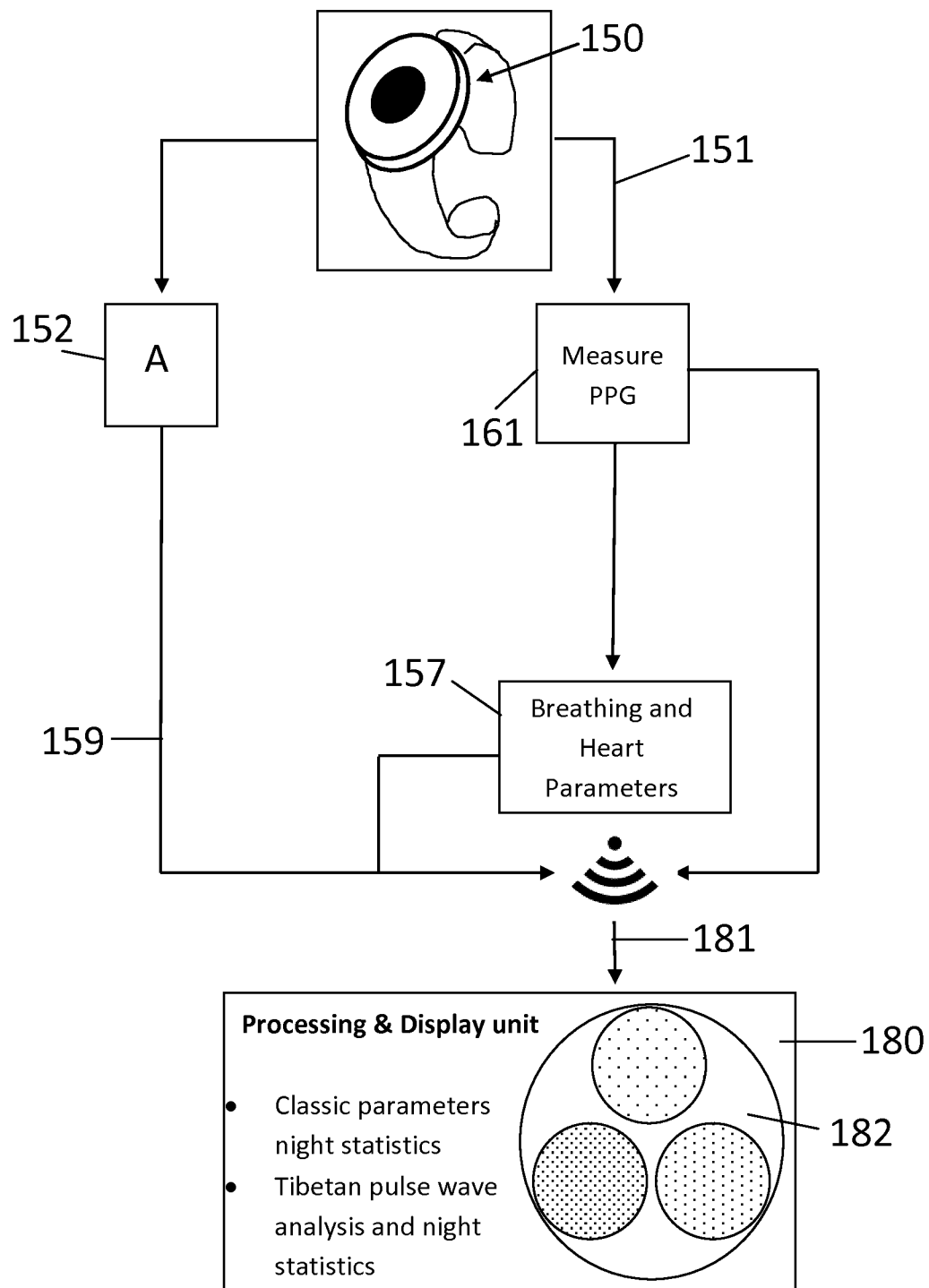


Fig. 10c

Table 2. T2D Qualitative Correspondences

DPW Measures → TTP Measures ↓	Rhythmicity	Stability	Examples of Waveform
Rate: Fast, slow, Gentle	x	x	Fast Gentle
Tension: Tense, Light, Rolling	x	x	Tense Rolling
Length: Long/Wide, Short/Sharp	x		Long Short
Amplitude: Small, Voluminous		x	Small Voluminous
Shape: Rough, Fine/Smooth/Soft		x	Rough Smooth

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/ EP2013/064678

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 1-17
because they relate to subject matter not required to be searched by this Authority, namely:
see FURTHER INFORMATION sheet PCT/ISA/2 10
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 64(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which the additional search fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fees were not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/064678

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/Q24 A61B5/00
ADD. A61B5/Q21

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/179011 AI (MOON JIM [US] ET AL) 12 July 2012 (2012-07-12) abstract paragraph [0060] - paragraph [0073] figures 6,7,24 -----	18-22
A	XU ET AL: "Baseline wander correction in pulse waveforms using wavelet-based cascaded adaptive filter" , COMPUTERS IN BIOLOGY AND MEDICINE, NEW YORK, NY, US, vol . 37, no. 5, 15 March 2007 (2007-03 -15) , pages 716-731, XP022016723 , ISSN : 0010-4825, DOI : 10.1016/J.COMPBIOMED.2006.06.014 the whole document -----	18-22



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

18 September 2013

Date of mailing of the international search report

25/09/2013

Name and mailing address of the ISA/

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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos. : 1-17

Claims 1-17 relate to a method of diagnosis on human or animal body, because they comprise the four steps acknowledged to form a diagnostic method practiced on the human or animal body. In claim 1, the step of 'sensing a pulse...' constitutes the examination phase, whereas the steps 'generating a digital pulse...' and 'determining one or more...' comprise both the comparison and finding of any significant deviation with standard value. Finally, the step of 'using the one or more features...' is considered to constitute the decision phase. This Authority is not required to search the present application with respect to the aforementioned claims (Article 17(2) (b) PCT and Rule 39.1(i v) PCT). Consequently, no International Search Report and no Written Opinion (Rule 67.1 PCT in combination with Rule 43bis.1(b) PCT) have been established with respect to them.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/064678

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012179011 AI	12-07-2012	US 2012179011 AI	12-07-2012
		WO 2013071014 A2	16-05-2013

专利名称(译)	一种用于确定人的状态的方法和系统		
公开(公告)号	EP2874539A1	公开(公告)日	2015-05-27
申请号	EP2013736568	申请日	2013-07-11
[标]申请(专利权)人(译)	瑞士定制手表		
申请(专利权)人(译)	瑞士定制手表		
当前申请(专利权)人(译)	瑞士定制手表		
[标]发明人	CELKA PATRICK		
发明人	CELKA, PATRICK		
IPC分类号	A61B5/024 A61B5/00 A61B5/021		
CPC分类号	A61B5/02108 A61B5/02405 A61B5/02416 A61B5/4854 F04C2270/0421		
优先权	2012001106 2012-07-20 CH		
外部链接	Espacenet		

摘要(译)

根据本发明，提供了一种用于确定人的状态的方法，包括以下步骤：使用光电容积描记器（PPG）传感器感测人的脉搏；产生表示感测脉冲的数字脉冲波形；从数字脉冲波形确定一个或多个特征；使用一个或多个特征来确定人的状态是以下之一或两者：1）三种心脏，呼吸和放松状况的混合；或2）三种藏族类型的混合：肺，Tripa和Beken。