US 20180090229A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2018/0090229 A1**

Sanyal et al. (43) **Pub. Date: Mar. 29, 2018**

(54) **AUTOMATED CONTINUOUS AND ADAPTIVE HEALTH MONITORING**

(71) Applicants: **Alodeep Sanyal**, San Jose, CA (US); **Benjamin Mbouombouo**, Saratoga, CA (US); **Sankha Bhattacharya**, San Jose, CA (US); **Nilanjan Banerjee**, Elkridge, MD (US); **Indranil Sen-Gupta**, Fullerton, CA (US)

(72) Inventors: **Alodeep Sanyal**, San Jose, CA (US); **Benjamin Mbouombouo**, Saratoga, CA (US); **Sankha Bhattacharya**, San Jose, CA (US); **Nilanjan Banerjee**, Elkridge, MD (US); **Indranil Sen-Gupta**, Fullerton, CA (US)

(21) Appl. No.: **15/829,877**

(22) Filed: **Dec. 2, 2017**

Related U.S. Application Data

(63) Continuation-in-part of application No. 15/636,073, filed on Jun. 28, 2017.

(60) Provisional application No. 62/355,507, filed on Jun. 28, 2016.

Publication Classification

(51) **Int. Cl.**

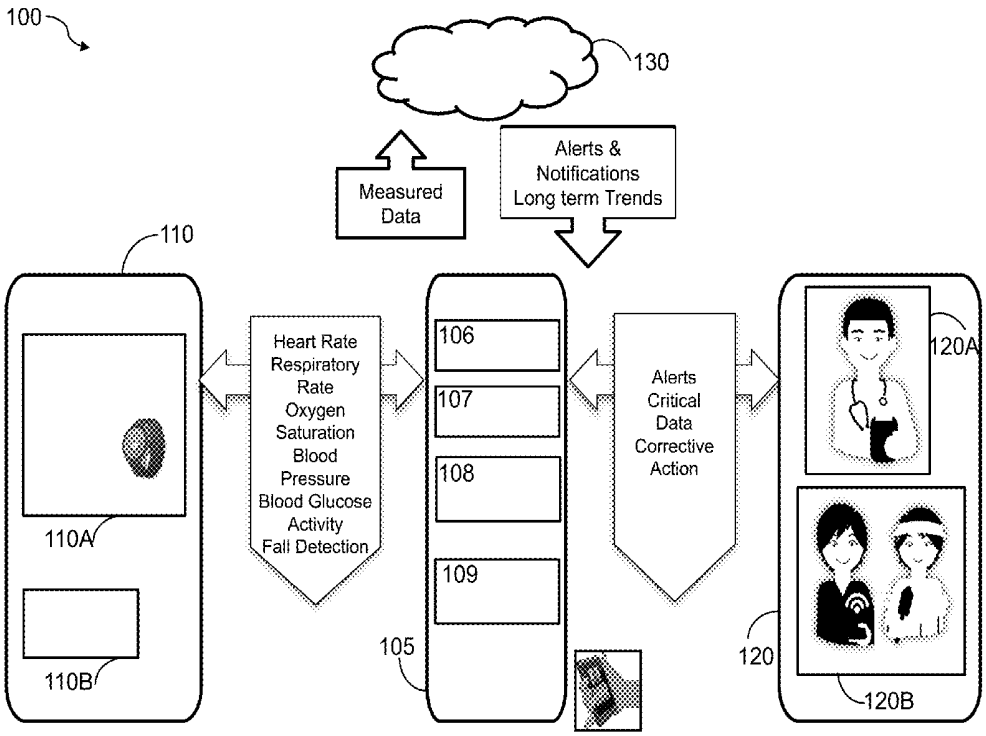
G16H 40/67	(2006.01)
G16H 50/30	(2006.01)
A61B 5/00	(2006.01)
A61B 5/0205	(2006.01)
A61B 5/02	(2006.01)
A61B 5/046	(2006.01)
A61B 5/0464	(2006.01)
A61B 5/16	(2006.01)

(52) **U.S. Cl.**

CPC ***G16H 40/67*** (2018.01); *A61B 5/021* (2013.01); ***A61B 5/0022*** (2013.01); ***A61B 5/0024*** (2013.01); ***A61B 5/02055*** (2013.01); ***A61B 5/02028*** (2013.01); ***A61B 5/046*** (2013.01); ***A61B 5/4818*** (2013.01); ***A61B 5/0464*** (2013.01); ***A61B 5/165*** (2013.01); ***A61B 5/4094*** (2013.01); ***A61B 5/4875*** (2013.01); ***A61B 5/4842*** (2013.01); ***A61B 5/681*** (2013.01); ***A61B 5/6803*** (2013.01); ***G16H 50/30*** (2018.01)

(57) **ABSTRACT**

A non-invasive health monitoring system comprises a wearable central sensor and at least one wearable remote sensor in wireless communication, a portable device readily accessible to the user, and a cloud platform. Each sensor collects batches of data indicative of one or more physiological parameters of the user at a physiological parameter-specific frequency, for a pre-defined time window. The central sensor receives and processes the measured data from each sensor, and stores processed data in a memory within the central sensor. The portable device comprises a receiver wirelessly receiving the processed data and instructions from the central sensor; a processor running a mobile application handling the processed data and instructions; and a transmitter. The cloud platform receives the processed data from the transmitter; analyzes the received processed data; and transmits the results to at least one of the portable device and an authorized healthcare entity.



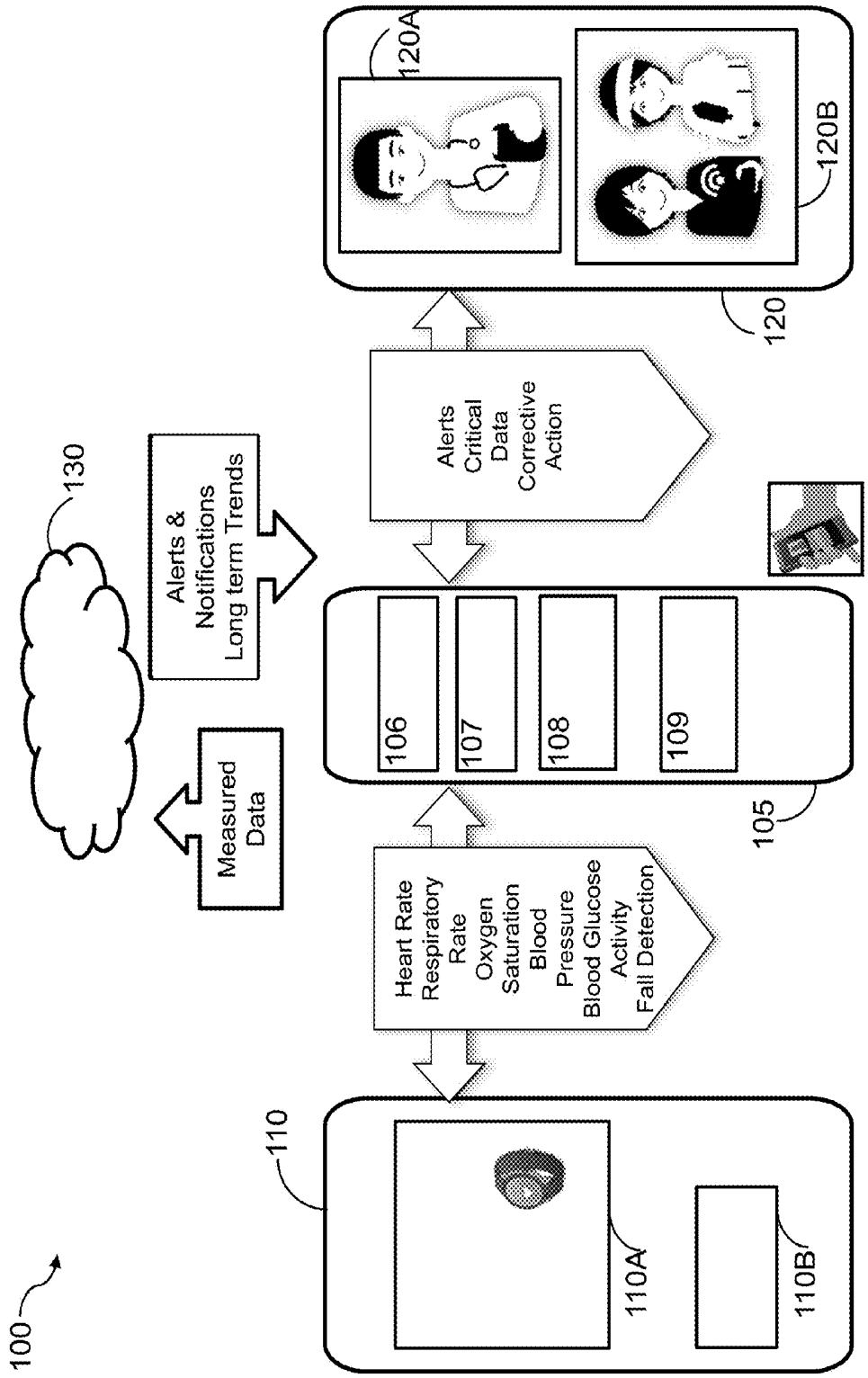

100
110
110A
110B
Heart Rate
Respiratory Rate
Oxygen Saturation
Blood Pressure
Blood Glucose
Activity
Fall Detection
Measured Data
105
106
107
108
109
Alerts Critical Data Corrective Action
Alerts & Notifications Long term Trends
130
120
120A
120B

Figure 1

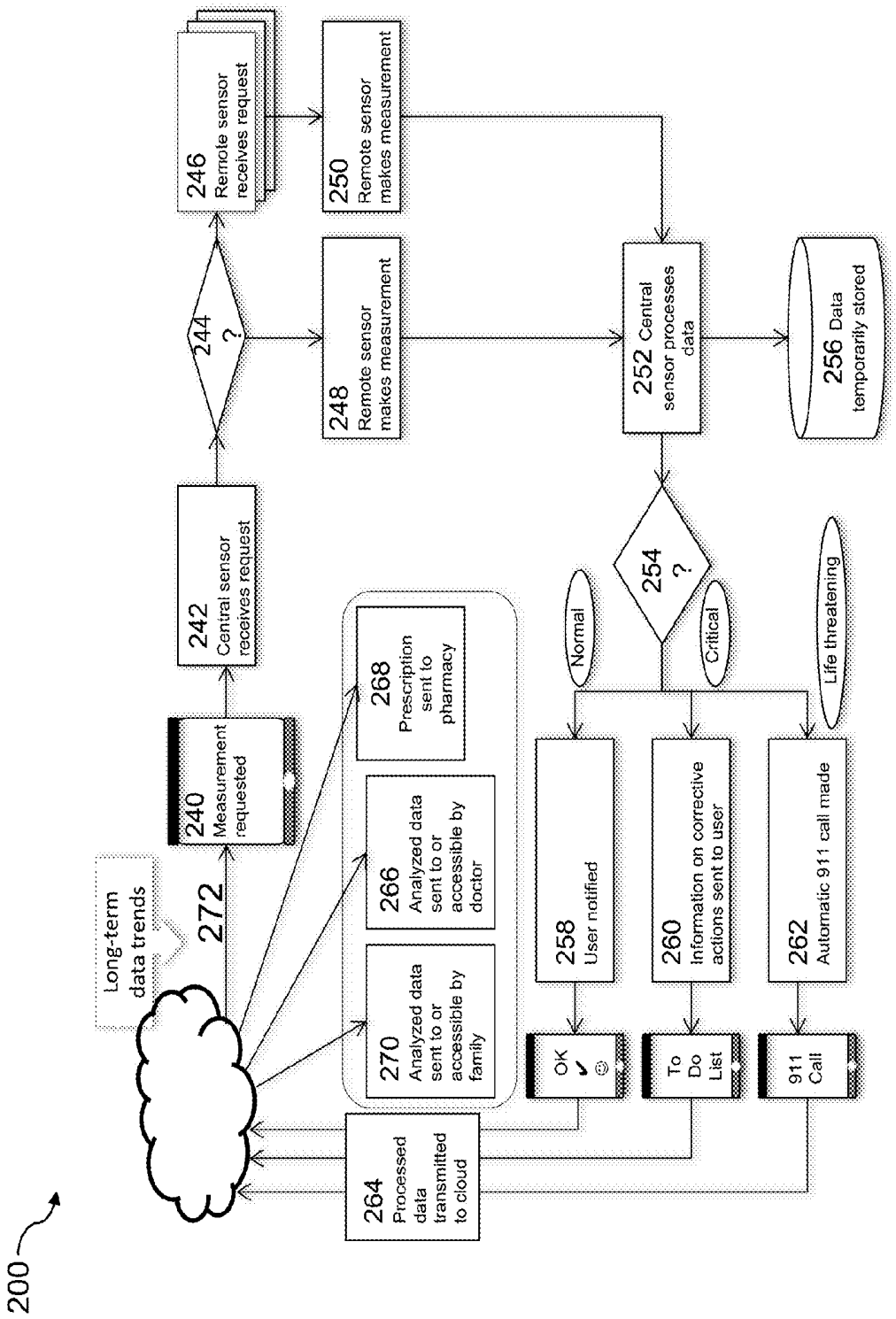

200
Long-term data trends
272
240 Measurement requested
242 Central sensor receives request
244 ?
246 Remote sensor receives request
248 Remote sensor makes measurement
250 Remote sensor makes measurement
252 Central sensor processes data
254 ?
256 Data temporarily stored
Normal
Critical
Life threatening
258 User notified
260 Information on corrective actions sent to user
262 Automatic 911 call made
OK
To Do List
911 Call
264 Processed data transmitted to cloud
268 Prescription sent to pharmacy
266 Analyzed data sent to or accessible by doctor
270 Analyzed data sent to or accessible by family

Figure 2

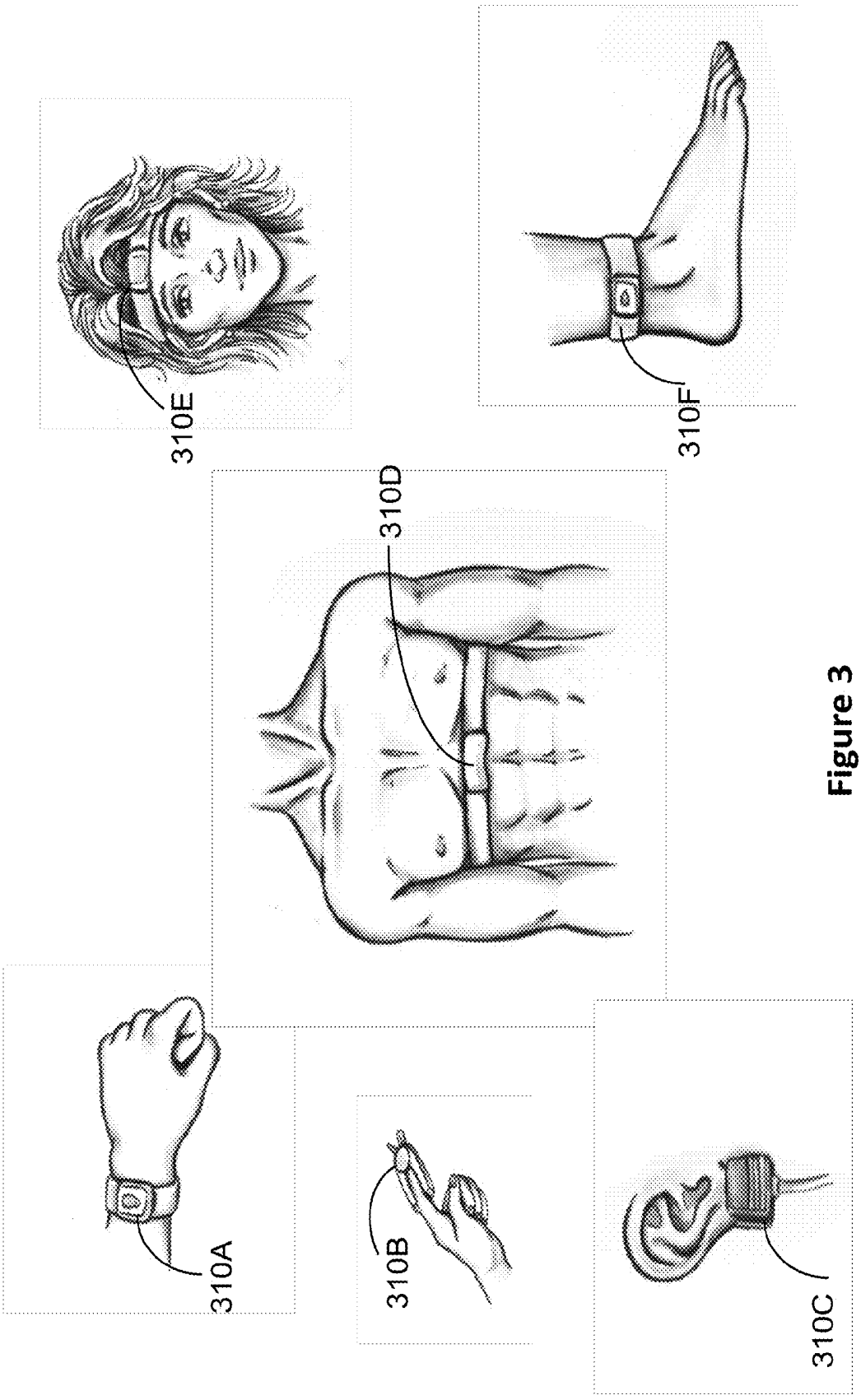
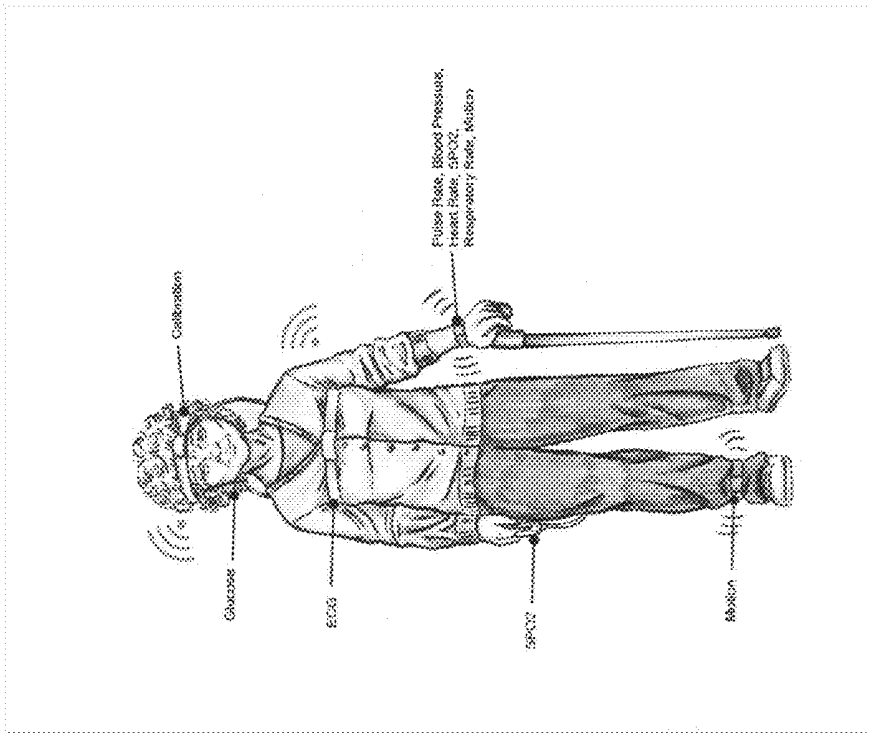


Figure 3


Pulse Rate, Blood Pressure,
Heart Rate, SPO2,
Respiratory Rate, Motion
Calibration
Glucose
ECG
SPO2
Motion

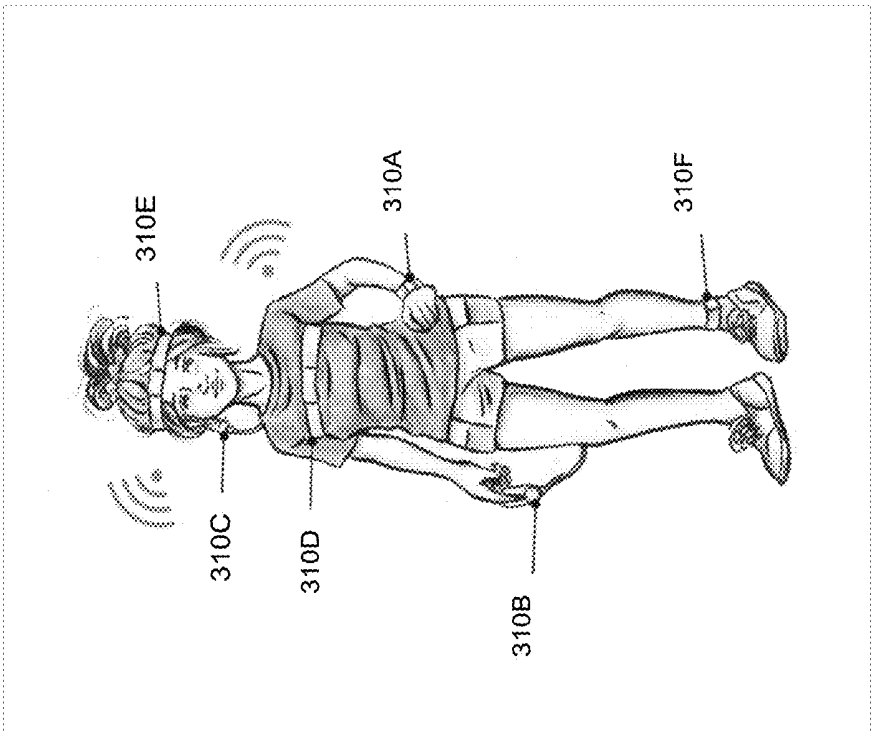

310E
310A
310F
310C
310D
310B

Figure 4

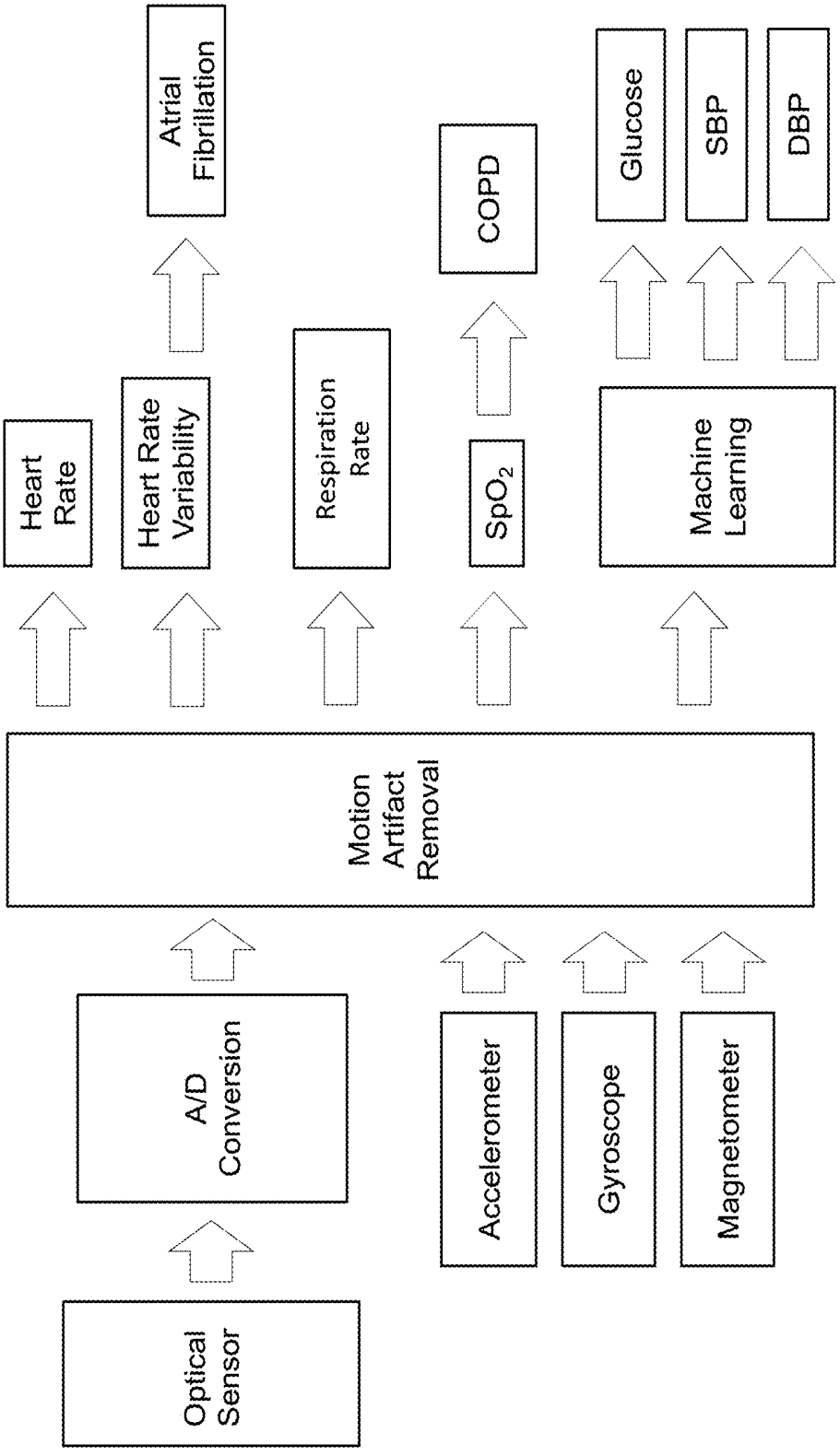

Optical Sensor
A/D Conversion
Accelerometer
Gyroscope
Magnetometer
Motion Artifact Removal
Heart Rate
Heart Rate Variability
Atrial Fibrillation
Respiration Rate
SpO2
COPD
Machine Learning
Glucose
SBP
DBP

Figure 5

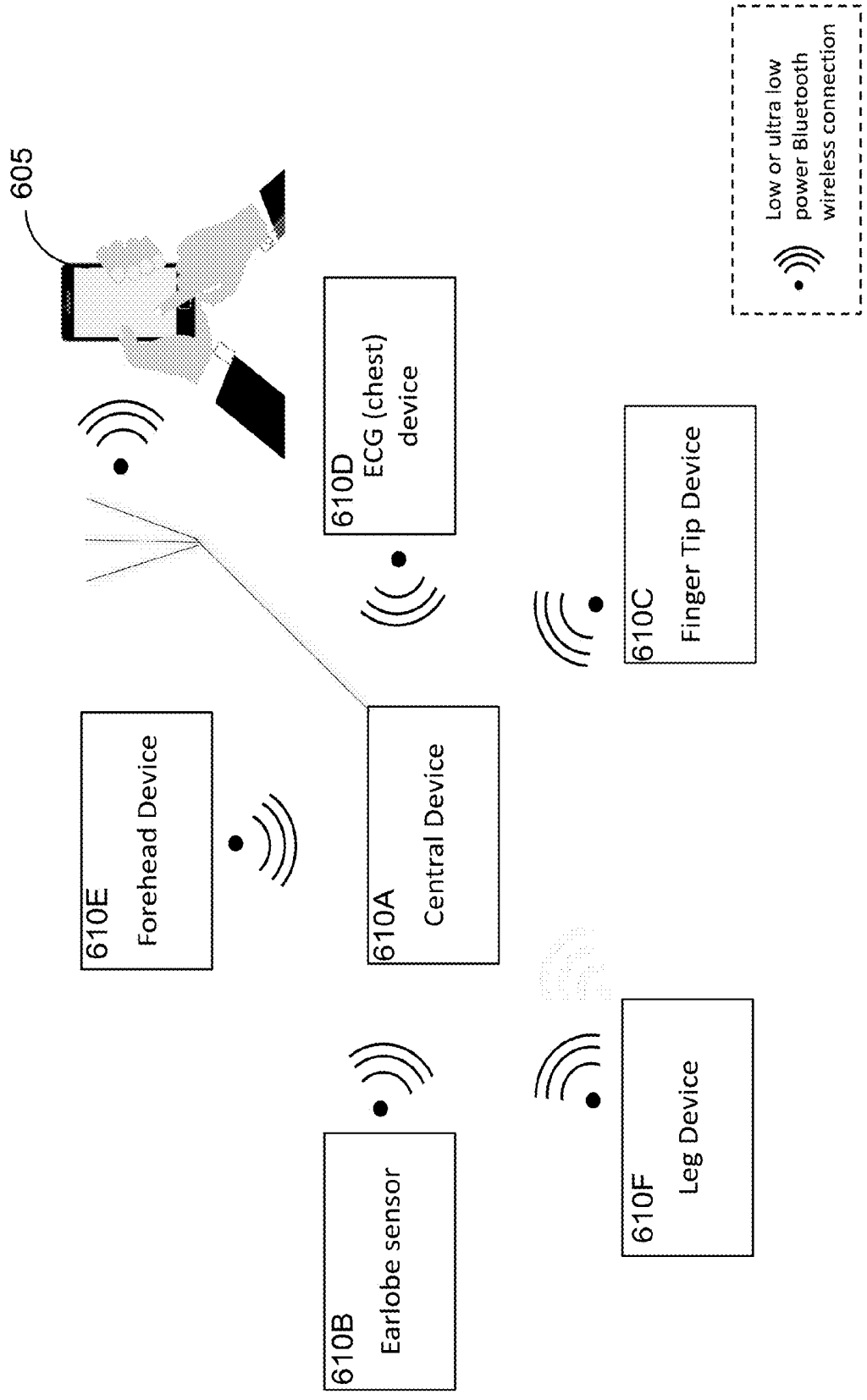

605
610E
Forehead Device
610A
Central Device
610D
ECG (chest)
device
610C
Finger Tip Device
610B
Earlobe sensor
610F
Leg Device
Low or ultra low
power Bluetooth
wireless connection

Figure 6

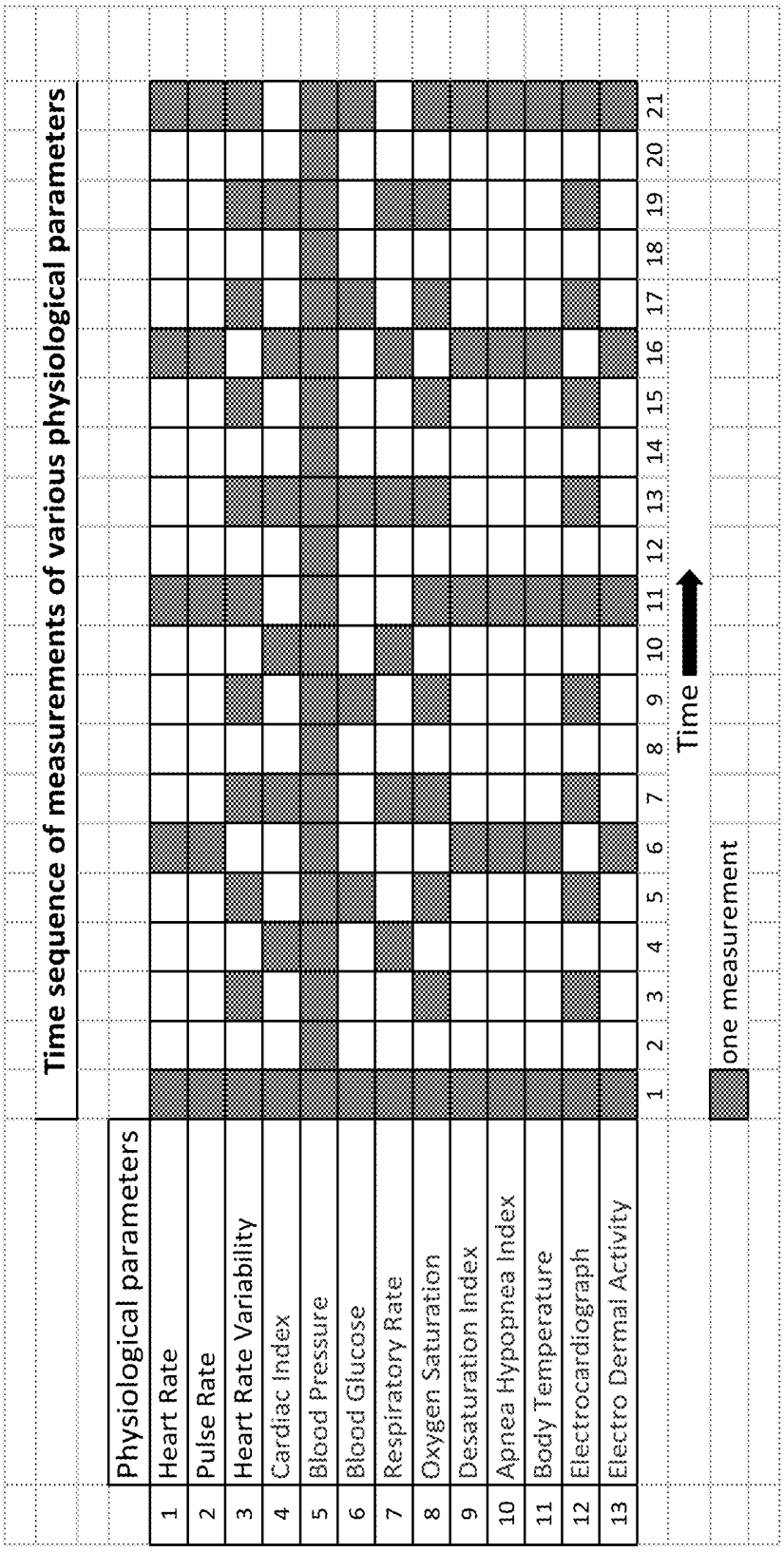

Time sequence of measurements of various physiological parameters
Physiological parameters
1 Heart Rate
2 Pulse Rate
3 Heart Rate Variability
4 Cardiac Index
5 Blood Pressure
6 Blood Glucose
7 Respiratory Rate
8 Oxygen Saturation
9 Desaturation Index
10 Apnea Hypopnea Index
11 Body Temperature
12 Electrocardiograph
13 Electro Dermal Activity
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time
one measurement

Figure7

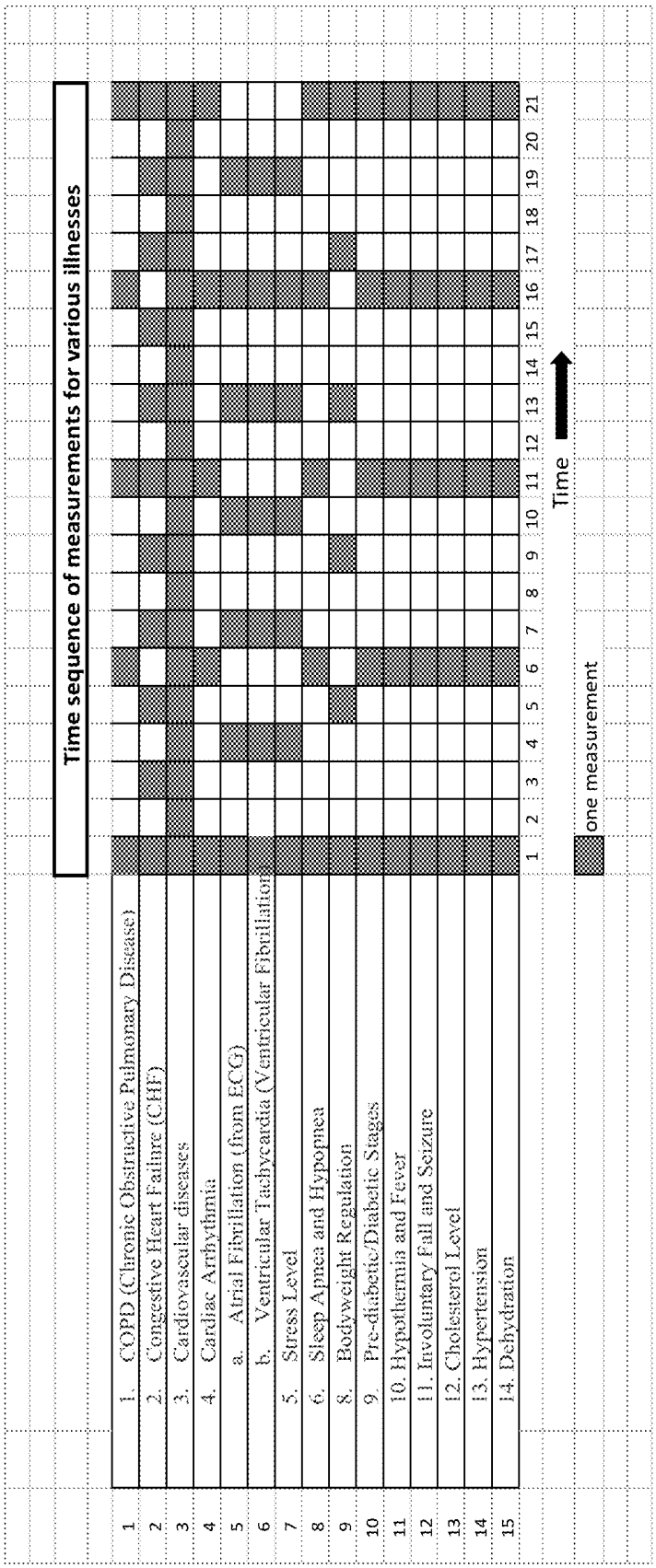

Time sequence of measurements for various illnesses
1. COPD (Chronic Obstructive Pulmonary Disease)
2. Congestive Heart Failure (CHF)
3. Cardiovascular diseases
4. Cardiac Arrhythmia
a. Atrial Fibrillation (from ECG)
b. Ventricular Tachycardia (Ventricular Fibrillation)
5. Stress Level
6. Sleep Apnea and Hypopnea
8. Bodyweight Regulation
9. Pre-diabetic/Diabetic Stages
10. Hypothermia and Fever
11. Involuntary Fall and Seizure
12. Cholesterol Level
13. Hypertension
14. Dehydration
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time
one measurement

Figure 8

AUTOMATED CONTINUOUS AND ADAPTIVE HEALTH MONITORING

CROSS-REFERENCE

[0001] This application is a continuation-in-part of U.S. application Ser. No. 15/636,073, filed Jun. 28, 2017, which in turn claims priority to Provisional Application No. 62/355,507, filed Jun. 28, 2016, both of which are incorporated herein by reference in their entirety, as if set forth in full in this application for all purposes.

OVERVIEW

[0002] A non-invasive multi-sensor eco-system tracks and monitors critical human physiological parameters, including those covered by the term "vital signs," to detect and predict health conditions. The system may be operated in an adaptive mode. The physiological parameters are extracted from a plurality of sensors using novel algorithms. The parameters measured by one embodiment may include blood pressure, heart rate, oxygen saturation (SpO2), respiratory rate, blood glucose level, body temperature and physical activity measured as step count.

[0003] The eco-system consists of multiple components wirelessly communicating with each other: (1) wearable sensors, which may include signal processing functionality as well as wireless inter-sensor communication and short-term data storage; (2) a portable computing device hosting a mobile application which enables reception of the processed sensed data, transmission of that data to a cloud platform for analysis, display of push notifications determined by the processed sensed data, reception of analysis results fed back from the cloud platform, and visualization of the processed sensed data and of the cloud analytics data; and (3) the cloud platform itself, allowing long-term data storage as well as analysis of the measurement data to obtain short and long-term health trends and future health predictions. In some embodiments the eco-system also includes a linked healthcare provider, for professional review and action as and when necessary or appropriate.

[0004] The eco-system operates to (a) analyze the physiological parameters derived from data provided by two or more sensors, positioned at different locations over the subject's body; (b) compare them against their respective normal, critical and life-threatening bounds as defined by the clinical community; and (c) provide feedback, alerts, push notifications and/or 911 calls depending on the criticality of the results of the comparison. Machine learning algorithms may be employed to carry out various aspects of the analysis, at the cloud platform level.

BACKGROUND

[0005] With the increase in the size of the elderly population, as well as the emergence of chronic diseases on a broader population segment, largely influenced by changes in modern lifestyle, coupled with rapid increase in healthcare costs, there has been a significant need to monitor the health status and overall wellbeing of individuals in their daily routine to prevent serious health disorders. Alongside, we observe an increase in thirst for quantification of one's own health on a continuous basis. The adoption of mobile healthcare technology promises to enhance the quality of life for chronic disease patients and the elderly, as well as healthy individuals. Furthermore, it offers the potential to alter the modality of the current healthcare system by enhancing the scope of out-patient care and by reducing the need for hospitalizations and other cost-intensive healthcare needs.

[0006] Some solutions have been proposed to address issues in this area, but none of them has provided a closed and comprehensive eco-system as envisaged by the present invention.

[0007] There is, therefore, a need for systems and methods that allow for continuous non-invasive health monitoring technology—a disruptive technology, in the sense that it would alter the perspective of healthcare from reactive to proactive. The eco-system would ideally be closed-loop and comprehensive, covering a spectrum of actions, from automatically collecting physiological parameters from each of a plurality of users, getting a full understanding of the parameter profile for each individual user, and recording their long-term health trends and conditions, to providing guidance toward attaining a healthier lifestyle for individual users, groups and the community as a whole.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** illustrates a high level view of an eco-system according to one embodiment of the invention.

[0009] FIG. **2** schematically illustrates the functioning of an eco-system according to one embodiment of the invention.

[0010] FIG. **3** illustrates examples of sensors that may be worn in various embodiments of the invention.

[0011] FIG. **4** illustrates two examples of subjects wearing sensors according to embodiments of the invention.

[0012] FIG. **5** illustrates the computational flow of data through some embodiments of the invention.

[0013] FIG. **6** illustrates low power connectivity between hardware elements in some embodiments of the invention.

[0014] FIG. **7** illustrates the time sequence of measurements of various physiological parameters for one user according to one embodiment of the invention.

[0015] FIG. **8** illustrates the time sequence of combinations of measurements of physiological parameters categorized according to the chronic illnesses or other health conditions experienced by one user according to one embodiment of the invention.

DETAILED DESCRIPTION

[0016] The manner in which the present invention provides its advantages over systems in current use can be more easily understood with reference to FIGS. **1** through **4**. It should be noted that throughout this disclosure, the words "user", "patient", and "subject" are used interchangeably.

[0017] FIG. **1** is a high level view of an eco-system **100** of the present invention, illustrating relationships between four major elements—sensors **110** (central sensor **110** A and just one remote sensor **110** B are shown in this example for simplicity, but in other embodiments, there may be additional remote sensors), a cloud platform **130** hosting AI-based analytics, and a mobile or portable device **105**. Device **105** has a user interface enabling communication with the sensors, the platform, and with an entity **120**, typically comprising a healthcare entity, which may, for example, be a physician, a clinic, or an emergency care unit. Entity **120** may also include a user chosen sub-community of people such as family members. These various elements make up a

closed or self-contained, independently functioning eco-system, which in this embodiment includes entity **120**. In some embodiments, entity **120** may be considered to lie outside the eco-system, but to be in communication with it. In the embodiment shown in FIG. **1**, a single healthcare entity **120**A is communicatively coupled to mobile device **105** and directly or indirectly to cloud platform **130**. In another embodiment, not shown, there may be two or more different healthcare entities, one in communication with the cloud platform and the other in communication with the mobile device.

[0018] FIG. **1** indicates how a system of continuous and adaptive vital data monitoring with clinical accuracy may result in a healthier lifestyle and peace of mind.

[0019] FIG. **2** illustrates the functioning of elements of an eco-system **200** according to the present invention, showing a finer granularity level than FIG. **1**, and illustrating some of the steps performed by components of the closed-loop ecosystem.

[0020] One element or category is a plurality of wearable sensors (**110** in FIG. **1**), including one central sensor and one or more auxiliary or remote sensors worn by a user. Each sensor is configured to monitor one of the user's physiological parameters. Examples of typical parameters of interest are listed in Table 1.

TABLE 1

1. Heart Rate
2. Pulse Rate
3. Heart Rate Variability
4. Cardiac Index
5. Blood Pressure
6. Blood Glucose
7. Respiratory Rate
8. Oxygen Saturation (SpO2)
9. Desaturation Index
10. Apnea Hypopnea Index
11. Body Temperature
12. Electrocardiograph Activity
13. Electro Dermal Activity

[0021] As shown in FIG. **2**, measurements of one or more of these parameters may be initiated at step **240**, as and when desired by the user, using an interface of an application on a convenient portable device easily accessed by the subject, such as a smart-phone (**105** in FIG. **1**). Alternately, the parameters may be automatically measured as programmed in such an application. Components of device **105** include receiver **106**, transmitter **107**, processor **108**, and display screen **109**.

[0022] The central sensor is typically worn on the wrist; typical locations for other sensors include the forehead, chest, fingertip, earlobe and leg. Examples of measurement technologies used include photoplethysmography (PPG), electrocardiography (ECG), 3-axis accelerometry, temperature measurement using thermistors, and electrodermal activity monitoring. Some of the sensors (often those at the forehead, earlobe and fingertip) may be used primarily or solely to provide calibration signals for other sensors.

[0023] FIG. **3** shows close up views of examples of sensors at their envisaged body locations. Sensor **310**A is a wrist-mounted sensor, typically the central sensor of the system. Sensors **310**B, **310**C, **310**D, **310**E, and **310**F are examples of sensors designed to be worn on "remote" locations such as a finger tip, earlobe, around the chest, head, or ankle respectively.

[0024] FIG. **4** illustrates how such sensors may be worn by two subjects at different stages of life. The wireless communication of data between the central sensor and each remote sensor may be carried out using Bluetooth or other well-known and established wireless technologies. The placement of sensors **310**A-F is shown on the youthful figure on the left, while the corresponding physiological parameters that may be measured using those sensors are shown on the elderly figure on the right. In different embodiments of the invention, a subset of the sensors shown may be used, with as few as one remote sensor present in addition to one central sensor.

[0025] In some embodiments, a single sensor may provide data indicative of more than one physiological parameter of interest. One example of this is a photoplethysmographic (PPG) sensor, which essentially monitors blood volume, but from which data indicative of SpO2, glucose, heart rate, blood pressure, and respiratory rate may be derived. Sensors may be operated to monitor the wearer's vital parameters continuously and automatically over long periods of time.

[0026] Returning to FIG. **2**, once the measurement instructions are issued at step **240** and received by the central sensor at step **242**, central sensor selects at step **244** which sensor or sensors are required to perform the desired measurement or measurements. If necessary, the request is transmitted to a remote sensor at step **246**. Each designated sensor (central or remote) performs the measurements of the corresponding parameter or parameters at steps **248** and/or **250** respectively. Any measurements performed by remote sensors (such as a leg sensor for example) are wirelessly sent to the central sensor (typically the sensor worn on the subject's wrist), with that central sensor taking responsibility for aggregating the other sensors' data as and when necessary, processing them at step **252**, as will be described in greater detail below, and transmitting the results to the user interface on the mobile device, typically a smart-phone.

[0027] Measurements are made up of batches of data, collected at a frequency that may be selected specifically for the physiological parameter being monitored, each batch of data being collected for a time window that may also be specific to the parameter. For example, measurements of a first parameter may be made up of a series of data points collected over 2-minute time windows, at a frequency of once per hour, while measurements of a second parameter may be made up of a second series of data points collected over 5-minute time windows at a frequency of once every 5 hours. The time taken to process mesurements for each parameter will in general be parameter-specific too, with blood glucose mesurements taking longer to process than pulse rate measurements, for example.

[0028] Calibration plays an important role in attaining clinical-grade accuracy for all measurements of physiological parameters. Two methods may be used to address the calibration issue:

[0029] 1. Static calibration: Measurement of a parameter using the proposed apparatus is compared against the gold standard (clinical setting measurement) and repeated for a large and diverse set of individuals. The measurement error computed is used to determine the calibration coefficients for the given parameter. The calibration coefficients thus obtained are applied to every apparatus manufactured. The calibration coefficients do not change for the lifetime of operation for a given apparatus.

[0030] 2. Dynamic AI-based calibration: The calibration coefficients of a given parameter are dynamically computed on cloud platform based on data from a large population bucketed according to age, sex, race, skin color, skin thickness etc. As new data points get added into a specific population bucket, the calibration coefficients get recomputed and adjusted into the settings of a given apparatus used by an individual. The calibration coefficients in this method get constantly adjusted and improved over the lifetime of the apparatus or device performing the parameter measurement of interest.

[0031] The second method, dynamic calibration, clearly provides some significant advantages in terms of specificity for the individual, and long term reliability. In the present invention, both static calibration—the current standard practice—and dynamic calibration may be used, to provide a desirable combination of accuracy, convenience, specificity and reliability.

[0032] Returning to FIG. **2**, at step **252**, as noted above, the central sensor processes (filters, calibrates, scales, etc) the raw data received to generate physiological parameter data with accuracies sufficient to render the parameter data clinically meaningful. Specially developed hardware-embedded algorithms may be used to achieve real-time signal processing. FIG. **5** schematically illustrates the computational flow of data gathered by various sensors, and processed by hardware-embedded algorithms according to some embodiments of the present invention, to yield data of clinical significance. The central sensor then compares those processed data values to values defining ranges of interest (typical ranges being normal, sub-critical, critical (or dangerous) and life-threatening) for each corresponding parameter, at step **254**. The measured and processed data may be stored for the short term in the memory of the central sensor, at step **256**. Depending on the results of the comparisons, the central sensor may wirelessly send push notifications to the smart-phone (or similar portable device). These notifications may be normal text, or in some embodiments, simple symbols or easily appreciated codes. For example, at step **258**, a blue code, or a predetermined symbol such as a smiley face may be sent to indicate to the subject that a parameter is within normal bounds, an orange code may be sent at stip **260** to indicate that the parameter is outside normal bounds but within critical bounds, or a red code may be sent at step **262** to indicate life-threatening bounds have been exceeded. In some embodiments, audible alerts may be issued as well as or instead of visible ones. In the case of a life-threatening situation (red alert), the smart-phone may automatically initiate a 911 call.

[0033] In some embodiments, not shown in this figure, alerts may be sent to medical professionals such as the user's personal physician, or to health centers or emergency services. In less serious cases, alerts may be sent just to the user, accompanied by recommendations on relevant corrective actions.

[0034] One advantage of the present invention is that the data processing and transmission burdens of the entire group of sensors is carried by just the central sensor, easing the power consumption and size, weight, complexity and cost demands on the remote sensors.

[0035] FIG. **6** schematically illustrates one embodiment in which ultra short range (0.5 m to 1 m), ultra low power (1 to 10 microwatt range) Bluetooth wireless connections are provided between central sensor **610**A and five remote sensors **610** B-F, and a slightly longer range (1.5 m) low power (100 microwatt to 300 microwatt) Bluetooth connection is provided between central sensor **610**A and mobile (in this case hand-held) device **605**. In other embodiments, other similar low and ultra low power protocols may be used. Reduced power consumption results in longer battery lifetime and reduced device heating, so better reliability.

[0036] At step **264**, the smart-phone (or other portable device) then uses the standard internet service (e.g. 4G, LTE, WiFi etc) to securely send the processed data to the cloud for long-term storage and analytics as will be described further below. It should be noted that the use of just one device—the smart-phone or similar device—to handle the transmission of processed data to the cloud significantly simplifies system design and power consumption relative to the situations common today, where each sensor of a plurality worn by a subject independently processes and transmits data to distant receivers. In the present invention, the remote sensors only have to transmit data over very short distances to reach the central sensor, which then sends processed data to the smart-phone, which in turn transmits them to the cloud, and receives other data (such as trend data discussed below) back. The display screen on the smart-phone (or PDA or tablet) allows the subject to receive push alerts and easily visualized displays of the results of the cloud-based analytics.

[0037] The cloud provides long term storage of the data received from the smart-phone, and carries out analysis using conventional and/or machine learning algorithms. The machine learning algorithms may be especially useful when applied to the stored physiological parameter data to provide information on long-term trends, and to yield personalized measurement data that are wirelessly sent back to the smart-phone.

[0038] The machine learning algorithms may also use the received and stored data regarding one or a combination of the parameters measured to determine health conditions or clinical insights (examples of which are listed below in Table 2) relevant to the individual subject. Predictions regarding future health may be made.

TABLE 2

1. COPD (Chronic Obstructive Pulmonary Disease)
2. Congestive Heart Failure (CHF)
3. Cardiovascular diseases
4. Cardiac Arrhythmia
   a. Atrial Fibrillation (from ECG)
   b. Ventricular Tachycardia (leading to Ventricular Fibrillation)
5. Stress Level
6. Sleep Apnea and Hypopnea
7. Personalized Meal Recommendation
8. Bodyweight Regulation
9. Pre-diabetic/Diabetic Stages
10. Hypothermia and Fever
11. Involuntary Fall and Seizure
12. Cholesterol Level
13. Hypertension
14. Dehydration

[0039] Specialized, in some cases unique, algorithms may be used to provide the determinations, insights, and predictions. Table 3 lists examples of some of the types of specialized algorithms envisaged. In some embodiments, the "normal" parameter ranges relative to which the wearer's parameters are compared may be customized according to sex, race, weight, height, and/or other characteristics. Data

may be analyzed over time and presented in a way that a user can monitor the progress of his/her health status for a given set of parameters.

TABLE 3

SpO2 extraction algorithm
Heart rate extraction algorithm
Heart rate variability extraction algorithm
Blood pressure extraction algorithm
Respiratory rate extraction algorithm
Blood glucose level extraction algorithm
Desaturation index computation algorithm
Cardiac index computation algorithm
Apnea Hypopnea index computation algorithm

[0040] As indicated by step **266** in FIG. **2**, the processed parameter data, trend data and clinical insights data (or some subset of such data) may be sent from the cloud directly or indirectly to a physician at a medical facility authorized by the subject to receive them. Upon reviewing the data, the physician may provide advice, guidance, education, and/or prescriptions to the patient (user). Prescriptions from the patient's doctor may then be wirelessly and securely sent via the cloud to a pharmacy pre-selected by the subject as part of his or her personal profile, the profile having been previously created by the subject at a secure website, accessed via the smart-phone or other computing device. Users can also update their profiles directly from a smart-phone.

[0041] As indicated by step **268**, some or all of the processed data may be sent from the cloud directly or indirectly to family members of the user, pre-authorized to receive such data.

[0042] The user's physician, other selected health professionals, family members, and others, make up a specific user-defined community, authorized to access data provided by the cloud platform relating to that user.

[0043] Analytics performed in the cloud can also provide long-term trends for vital parameters and clinical insights to a subject. These long-term trends consist of vital parameters measured over the course of many months or event years that is displayed in a receiver like a smart-phone, a tablet, or a computer.

[0044] As indicated by step **272**, the analytics carried out at the cloud may result in suggestions, transmitted back to the user via the smart-phone, for adjusting the sequence and/or frequency of measurements of particular parameters. The system may even request additional measurements of the same or other parameters if the previous measurements deviate from the predefined user specific range. For instance, an elevated temperature can trigger the automatic measurement of blood pressure, ECG, oxygen saturation, etc.

[0045] In this way and others discussed above or readily envisaged in the light of this disclosure, the eco-system can be adaptive, responding to current measurement data in the light of past data from the same subject and/or other comparable subjects, whether to appropriately instigate future measurements, inform the subject of trends, or to add to the physician's knowledge base enabling more effective guidance and treatment.

ADDITIONAL EXAMPLES AND DETAILS

(1) Hardware Embedded Algorithms for Real-Time Vital Signal Processing

[0046] Unique mathematical algorithms will process the raw PPG signal generated by the LED/Photo-Diode/AFE
[0047] SpO2 extraction algorithm
[0048] Heart rate extraction algorithm
[0049] Heart rate variability extraction algorithm
[0050] Blood pressure extraction algorithm
[0051] Respiratory rate extraction algorithm
[0052] Blood glucose level extraction algorithm
[0053] Desaturation index computation algorithm
[0054] Cardiac index computation algorithm
[0055] Apnea Hypopnea index computation algorithm

(2) Application for Smart Phone, Tablets, Laptop as User Interface, Data and Alerts Display

Alert System

[0056] The alert system has different severity level visualized by different colors
[0057] Color green means a specific vital parameter is within the normal range
[0058] Color yellow means that a specific vital parameter has exceeded the normal bounds but within a critical range
[0059] Color orange means that a specific vital parameter has exceeded the critical bounds but still below the life-threatening range
[0060] Color red means a specific vital parameter has exceeded the life-threatening bounds and an emergency call (such as, the 911 call in US) is automatically initiated.
[0061] A red alert is automatically issued for any life-threatening situation. In this case, a central monitoring facility first tries to establish a contact with the user, and upon no response, an emergency call (such as the 911 in US) is issued with a message about the location of the patient and the specific body parameter(s) in question. This will ensure the correct paramedic team with the correct equipment arrive at the scene on time and well prepared to save the life of the patient. The red alert is handled in an automatic way to address cases where a patient is unconscious and cannot make an emergency call (such as, 911) or even express him/herself. The user can also issue a red alert if a vital parameter is in a life-threatening range and the system has not yet issued a 911 call.

User Interface

[0062] User can enter personal information called user profile
[0063] User can request instant measurement of specific vital parameter
[0064] User can request to view trend data

(3) Analytics: Software and Machine Learning Algorithms for Data Pattern and Trend Analysis

[0065] The cloud-based analytics platform allows for the secured collection and long-term hosting of all personalized vital parameter data. It allows for
[0066] The creation of new multi-parameter machine learning algorithms to automatically derive the current state of various physiological vital parameters [002] and related health conditions for an individual user

[0067] Automatic derivation of deviations from the baseline for each of these parameters

[0068] Automatic derivation of a long-term trend for each of the vital parameters

[0069] Automated alerts that go out from the cloud back to the users, family and medical support staff

[0070] Derivation of gradual changes in baselines only observed over long periods of time

[0071] Prediction of future health-critical events for an individual user based on her own health data points and a population of health data (from a population bucket of individuals similar to the user in context) annotated with respective health-critical events

[0072] Special software algorithms developed to use the incoming vital sign data or combination of multiple vital signs data to provide long-term trends and insights for various health conditions.

[0073] Personalized subject vital sign monitoring: Other embedded algorithms will study a subject body to adjust the sequence or frequency of measurements of vital parameters. This specific data is personalized to a subject's health status.

[0074] Derivation of secondary health insights (such as body weight, body hydration level) from the primary vital parameters.

[0075] Creation of a personalized scoring and recommendation of food items based on their impact on various vital parameters.

[0076] Derivation of functioning status and health of major organs (such as liver, pancreas, and kidney) from the primary vital parameters measured. For liver health, enzyme levels in the blood critical for proper functioning of this organ can be detected, the parameters to track are Aspartate Aminotransferase (AST), Alanine Aminotransferase (ALT), alkaline phosphatase, bilirubin, albumin and total protein. For kidney health, the parameters to track are Blood Urea Nitrogen (BUN), creatinine, estimated glomerular filtration rate, and for the pancreas health, the important parameters are Amylase, Lipase and Calcium.

[0077] Derivation of various vitamin levels in blood from the primary vital parameters measured.

[0078] Derivation of blood parameters possibly indicating an elevated risk of presence of some form of cancer cells on the body from primary vital parameters measured. Some specific blood parameters include alkaline phosphatase, Lactate dehydrogenase (LDH), carcinoembryonic antigen (CEA), and prostate-specific antigen (PSA).

[0079] Derivation of other blood parameters, such as blood albumin level, amount and changes in Flavin, which can be useful in determining changes in different enzymatic levels, blood pH levels and anemic conditions. Changes in lipid levels will be used to show the trend of arterial blockages.

(4) Personalized Health Monitoring System Adaptive to Individual Physique and Lifestyle (PHMSYSTEM):

[0080] An individual is many ways different physically compared to every other person and also the lifestyle choices of that person over a period of time and the changes thereof reflect on all vital health parameters measured instantaneously and/or over a time period. The apparatus described in this patent when used by an individual, "learns" about the user's unique physique and lifestyle choices over a period of time and adjusts its pattern of measurement of vital parameters. These changes in measurement patterns over time affect the overall operating efficiency of the apparatus (such as battery power consumption and heating). These changes help the apparatus become more adaptive to an individual with the continuous use of it and "blends" into the unique patterns of life of that individual. The enhancement of the quality of life of any given individual is a key outcome of the individual adaptive nature of this system. The apparatus is capable of being set into different operating modes such as an adaptive mode (as described above), a traditional mode where every measurement occurs at certain frequency, and a continuous mode where the apparatus keeps taking measurements on a continuous basis.

(5) Individualized Food and Nutrition with the Help of Adaptive Personal Health Monitoring

[0081] Food and nutrition are keys to status of health of an individual. An individually adaptive personalized health monitoring system is at the center of personalization and individualization of nutrition. The proposed apparatus starts to "learn" about the effects of various food items on the measured vital health parameters of an individual as soon as the individual starts to use it. Over a period of time the apparatus acquires adequate "knowledge" of impact of various food items on the individual's overall wellbeing and estimates trend of health based on the eating habit and recommendations on how to improve it.

(6) Continuous and Adaptive Health Monitoring as a Service (CAHMaaS)

[0082] While most healthy people do not monitor their vital data at all between yearly medical checkups and various medical appointments, those suffering from non-life threatening chronic disease requiring continuous monitoring are not as consistent in doing so as recommended by medical professionals. CAHMaaS® offer the possibility to continuously monitor one's vital data through the use of a wearable device that measures vital data and saves them in a secured cloud server. The collected data are then analyzed through advanced analytics to offer the users real time clinical insights, adapted to the specific conditions of each user through the use of machine learning algorithms. The use of CAHMaaS® requires monthly and/or yearly subscription as well as the ownership of a device providing the required measurements. CAHMaaS® is in the context of Internet-of-life or an embodiment of Internet-of-life. The service based health monitoring system is at the heart of individual adaptiveness of the device to every user's unique physique and lifestyle over a period of time. The individualized adaptive system would help create a tailored ecosystem for individual consumer, the ecosystem might comprise of many things like personal wellness program, customized nutrition etc, the "tailored ecosystem" as one key application as a direct result of CAHMaas.

(7) Sensors

Central Device at Wrist (PPG)

[0083] (1) LED (optical signal transmitter)

[0084] (2) Photodiode (optical signal receiver)

[0085] (3) Analog Module (signal amplification and A/D conversion)

[0086] (4) MicroProcessing Unit (finite state machine, integer/FP units, data path)

[0087] (5) Memory

[0088] (6) Host Controller Interface (HCI)
[0089] (7) Low-power Bluetooth Interface
[0090] (8) Three-axis Accelerometer (3D positioning)
[0091] (9) Thermistor/Thermopile
[0092] (10) Battery and charger unit

Remote Device at Chest (ECG)

[0093] The chest apparatus collects ECG signals that will be wirelessly sent to the central apparatus for further processing and storage.

Remote Device at Earlobe

[0094] The earlobe apparatus is used to collect data that gets wirelessly sent to the central apparatus to calibrate other vital signs for better accuracy.

Remote Device at Finger Tip

[0095] The finger tip apparatus is used to collect data that gets wirelessly sent to the central apparatus to calibrate other vital signs for better accuracy.

Remote Device at Leg

[0096] The three-axis accelerometer is strapped at the bottom leg part to monitor the leg movements to process a 3-dimentional position of the user that is wirelessly communicated to the central apparatus

Remote Device at Forehead

[0097] The forehead apparatus is used to collect data that is wirelessly sent to the central apparatus to calibrate other vital signs for better accuracy.

(8) Automatic Measurement Frequency Adjustment Based on Considerations of Criticality and Severity

[0098] Ranges of criticality (normal, sub-critical, critical, dangerous, and life-threatening) may be defined by bounds as mentioned above, these bounds being stored in the memory of the central sensor, worn by the user. and used by the central sensor in processing measured data. Bounds for each parameter of interest (such as those listed in Table 1) may be defined separately for each individual user. In some embodiments, the memory is a Read Only Memory. Whereas normal is a healthy status, pre-critical is a range out of a heMthy status but not dangerous yet, critical is a status threatening the functionality of specific organ(s), and life threating is a status where life is not sustainable for human body.

[0099] First, the central sensor processor compares the collected data with the different limits of criticality for the individual to determine the level of criticality for every measured physiological parameter. Next, if necessary based on the determined level of criticality, the central sensor generates and sends instructions to the relevant sensor to adjust the frequency at which subsequent measurements of that parameter are made. The frequency of measurement ranges from lowest for normal range (for instance one measurement every 5 hours) to highest for life threatening (for instance one measurement every hour).

[0100] This continuous comparison of collected data and automatic adjustment of collection frequency makes the system truly adaptive, learning and self-controlling, based on stored and new information. For a given subject with a vital parameter (e.g. heart rate) that is within normal bounds, the frequency of measurement is automatically adjusted (if not already there) to the lowest value (for instance one heart rate measurement every 5 hours); for the same subject, where another physiological parameter (e.g. blood glucose) has crossed a critical limit, the frequency of measurement may be increased (for instance, one glucose measurement every 2 hours).

[0101] FIG. **7** illustrates the time sequence of measurements of various physiological parameters for one user according to one embodiment of the invention, showing how the frequency at which measurements are made may differ for different parameters. In the case of this individual, blood pressure measurements are taken at the highest frequency, once during each and every time window indicated by the numbers 1, 2, etc along the horizontal time axis, measurements of oxygen saturation are taken during every other time window, and measurements of electro dermal activity are taken at the lowest frequency, only once in every fifth time window.

[0102] In this particular case, for simplicity, the time windows are shown as if they are all equal, but in general, the time windows may be different for different parameters, the time required to collect and process a measurement of blood glucose, for example, typically being much longer than the time for a measurement of heart rate. For a given time interval (indicated as 1, 2, etc along the horizontal time axis) then, the time taken for one measurement may not occupy the whole time interval.

[0103] In some embodiments, the comparison of collected data with limits of criticality may be particularly useful when specific combinations of parameters are considered, allowing any of various health conditions or chronic illnesses, such as those listed in Table 2, to be detected or predicted. The level of severity of the health condition or illness may then be determined, based on such comparisons for the relevant group of parameters. Based on this determination, the central sensor may generate and send instructions to the relevant sensor or sensors to adjust the frequency at which subsequent measurements of those parameters, relevant to that health condition or illness, are made.

[0104] FIG. **8** illustrates the time sequence of combinations of measurements of physiological parameters categorized according to the chronic illnesses or other health conditions experienced by one user according to one embodiment of the invention. In the case of this individual, measurements of parameters particularly relevant to cardiovascular disease are taken at the highest frequency, once during each and every time window indicated by the numbers 1, 2, etc along the horizontal time axis, measurements of parameters indicative of stress are taken during every third time window, measurements of parameters indicative of body wieight regulation issues are taken every fourth time window, and measurements of parameters particularly relevant to COPD are taken at the lowest frequency, only once in every fifth time window.

[0105] Taking one particular example, for a given subject with a chronic illness (e.g. hypertension) that is within normal bounds, the frequency of measurements of each of the two physiological parameters used to derive this chronic illness is automatically adjusted to the lowest (for instance one systolic and diastolic blood pressure measurement every 5 hours); however, if the same subject has another chronic illness (e.g. COPD) that is within critical bounds, the fre-

quency of measurements of the physiological parameters used to derive this chronic illness is increased (for instance, one measurement of sp02 and respiration rate every 2 hours).

[0106] In this way, the frequencies of measurement of parameters relevant to any of the chronic illnesses of interest may be made continuously self-adjusting, as a function of criticality of the measured parameter values and the severity of the illness.

[0107] The above-described embodiments should be considered as examples of the present invention, rather than as limiting the scope of the invention. Various modifications of the above-described embodiments of the present invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings.

What is claimed is:

1. A non-invasive health monitoring system comprising:

a wearable central sensor and at least one wearable remote sensor in wireless communication with the central sensor, each sensor being configured to collect batches of data indicative of one or more physiological parameters of the user at a physiological parameter-specific frequency, each batch of data being collected for a physiological parameter-specific time window, wherein the central sensor is configured to receive and process the measured data from each of the remote sensors, to process data measured by the central sensor, and to store processed data from the remote sensors and the central sensor in a memory within the central sensor;

a portable device readily accessible to the user, the portable device comprising:

a receiver configured to wirelessly receive the processed data and instructions from the central sensor;

a processor running a mobile application handling the processed data and instructions; and

a transmitter configured to transmit the processed data; and a cloud platform configured to:

receive the processed data from the transmitter;

analyze the received processed data; and

transmit the results of the analysis to at least one of the portable device and an authorized healthcare entity.

2. The non-invasive health monitoring system of claim **1**, wherein criticality bounds for each of the one or more physiological parameters are stored in the memory, and wherein processing the measured data by the central sensor comprises comparing the measured data for each physiological parameter with corresponding criticality bounds for that physiological parameter.

3. The non-invasive health monitoring system of claim **2**, wherein for each parameter, the physiological parameter-specific frequency at which corresponding batches of data are collected is automatically adjusted, according to the comparison of the measured data for that parameter with the corresponding stored criticality bounds for that parameter.

4. The non-invasive health monitoring system of claim **2**, wherein the stored criticality bounds define normal, critical and life-threatening states.

5. The non-invasive health monitoring system of claim **4**, wherein the stored criticality bounds additionally define sub-critical and dangerous states.

6. The non-invasive health monitoring system of claim **2**, wherein the stored criticality bounds are defined for the user, independent of criticality bound for any other individual.

7. The non-invasive health monitoring system of claim **1** wherein processing the measured data by the central sensor comprises processing data for more than one physiological parameter to do at least one of detecting, assessing and predicting one or more specific health conditions or Chronic illnesses.

8. The non-invasive health monitoring system of claim **7**, wherein the specific health conditions or chronic illnesses comprise at least one of COPD (Chronic Obstructive Pulmonary Disease), Congestive Heart Failure (CHF), Cardiovascular diseases, Cardiac Arrhythmia, Atrial Fibrillation (from ECG), Ventricular Tachycardia (leading to Ventricular Fibrillation), Stress Level, Sleep Apnea and Hypopnea, Pre-diabetic/Diabetic Stages Hypothermia and Fever, involuntary Fall and Seizure, Cholesterol Level, Hypertension, and Dehydration.

9. The non-invasive health monitoring system of claim **7**, wherein criticality bounds for each of the one or more physiological parameters are stored in the memory, and wherein processing the measured data by the central sensor comprises comparing the measured data for each physiological parameter relevant to a specific health condition or chronic illness with corresponding criticality bounds to determine the level of severity of that health condition or chronic illness.

10. The non-invasive health monitoring system of claim **9**, wherein for each parameter relevant to a specific health condition or chronic illness, the physiological parameter-specific frequency at which corresponding batches of data are collected is automatically adjusted, for parameters, according to the determined level of severity of that health condition or chronic illness, independent of any adjustment for any other health condition or chronic illness.

11. The non-invasive health monitoring system of claim **2**, wherein each physiological-parameter-specific frequency may automatically change over time, determined by a time history of data collected from the user.

12. The non-invasive health monitoring system of claim **1**, wherein each remote sensor wirelessly communicates only with one wearable central sensor, minimizing system power consumption.

13. A method of non-invasively tracking a user's physiological parameters; the method comprising:

providing the user with a wearable central sensor and at least one wearable remote sensor in wireless communication with the central sensor, each sensor configured to collect batches of data indicative of one or more physiological parameters of the user at a physiological parameter-specific frequency, each batch of data being collected for a physiological parameter-specific time window, wherein the central sensor is configured to receive and process the measured data from each of the remote sensors, to process data measured by the central sensor, and to store processed data from the remote sensors and the central sensor in a memory within the central sensor;

providing the user with a mobile application, configured to run on a portable device readily accessible to the user; and

establishing a cloud platform configured to receive the processed data wirelessly transmitted from the portable device under the control of the mobile application, to analyze the received processed data, and to wirelessly

transmit the results of the analysis to at least one of the portable device and an authorized healthcare entity.

14. The method of claim **13**, wherein criticality bounds for each of the one or more physiological parameters are stored in the memory, and wherein processing the measured data by the central sensor comprises comparing the measured data for each physiological parameter with corresponding criticality bounds for that physiological parameter.

15. The method of claim **14**, wherein for each parameter, the physiological parameter-specific frequency at which corresponding batches of data are collected is automatically adjusted, according to the comparison of the measured data for that parameter with the corresponding stored criticality bounds for that parameter.

16. The method of claim **14**, wherein the stored criticality bounds define normal, critical and life-threatening states.

17. The method of claim **14**, wherein the criticality bounds are defined for the user, independent of criticality bounds for any other individual.

18. The method of claim **13** wherein processing the measured data by the central sensor comprises processing measured data for more than one physiological parameter to do at least one of detecting, assessing and predicting one or more specific health conditions or chronic illnesses.

19. The method of claim **18**, wherein criticality bounds for each of the one or more physiological parameters are stored in the memory, and wherein processing the measured data by the central sensor comprises comparing the measured data for each physiological parameter relevant to a specific health condition or chronic illness with corresponding criticality bounds to determine the level of severity of that health condition or chronic illness.

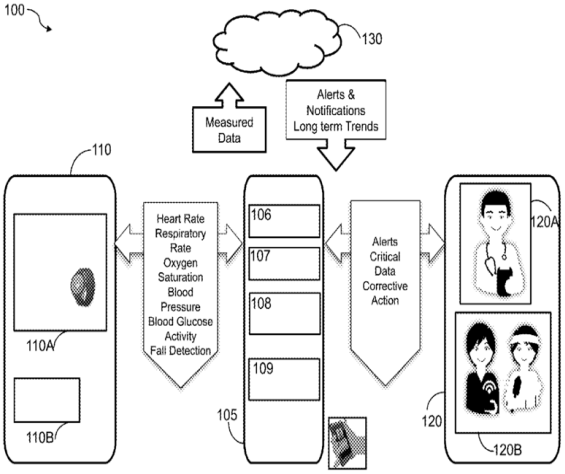
20. The method of claim **19**, wherein for each parameter relevant to a specific health condition or chronic illness, the physiological parameter-specific frequency at which corresponding batches of data are collected is automatically adjusted, for parameters, according to the determined level of severity of that health condition or chronic illness, independent of any adjustment for any other health condition or chronic illness.

* * * * *

专利名称(译)	自动连续和适应性健康监测		
公开(公告)号	US20180090229A1	公开(公告)日	2018-03-29
申请号	US15/829877	申请日	2017-12-02
[标]申请(专利权)人(译)	alodeep Sanyal MBOUOMBOUO BENJAMIN 班纳吉NILANJAN		
申请(专利权)人(译)	亚尔，ALODEEP MBOUOMBOUO，BENJAMIN 班纳吉NILANJAN		
当前申请(专利权)人(译)	亚尔，ALODEEP MBOUOMBOUO，BENJAMIN 班纳吉NILANJAN		
[标]发明人	SANYAL ALODEEP MBOUOMBOUO BENJAMIN BHATTACHARYA SANKHA BANERJEE NILANJAN SEN GUPTA INDRANIL		
发明人	SANYAL, ALODEEP MBOUOMBOUO, BENJAMIN BHATTACHARYA, SANKHA BANERJEE, NILANJAN SEN-GUPTA, INDRANIL		
IPC分类号	G16H40/67 G16H50/30 A61B5/00 A61B5/0205 A61B5/02 A61B5/046 A61B5/0464 A61B5/16		
CPC分类号	G16H40/67 G16H50/30 A61B5/0022 A61B5/0024 A61B5/02055 A61B5/02028 A61B5/046 A61B5/4818 A61B5/0464 A61B5/165 A61B5/4094 A61B5/4875 A61B5/4842 A61B5/681 A61B5/6803 A61B5/021 A61B5/02405 A61B5/0531 A61B5/0816 A61B5/14532 A61B5/14551 A61B2560/0475 A61B5/01 A61B5/1117 A61B5/14546 A61B5/02416 A61B5/0404 A61B5/0488 A61B5/0533 A61B5/1114 A61B5/6814 A61B5/6816 A61B5/6823 A61B5/6826 A61B5/6828 A61B5/6829 A61B5/7267 A61B5/7275 A61B5/74 A61B5/746 A61B2560/0209 A61B2560/0223 G06N20/00 G06Q10/06 G06Q50/22 G16H20/17 G16H20/30 G16H20/60 G16H50/20 G16H80/00 H04L67/04 H04L67/12 H04L67/125 H04L67/22 H04L67/30 H04M1/7253		
优先权	62/355507 2016-06-28 US		
外部链接	Espacenet USPTO		

摘要(译)

非侵入式健康监测系统包括可穿戴中央传感器和至少一个无线通信的可穿戴遥感器，用户容易接近的便携式设备以及云平台。每个传感器在预定义的时间窗口内以生理参数特定频率收集指示用户的一个或多个生理参数的批量数据。中央传感器接收并处理来自每个传感器的测量数据，并将处理后的数据存储在中央传感器内的存储器中。便携式设备包括无线接收来自中央传感器的经处理的数据和指令的接收器;运行处理经处理的数据和指令的移动应用程序的处理器;和一个发射器。云平台从发射机接收处理后的数据;分析收到的处理数据;并将结果传输到便携式设备和授权的医疗保健实体中的至少一个。


100
130
Measured Data
Alerts & Notifications Long term Trends
110
110A
110B
Heart Rate
Respiratory Rate
Oxygen Saturation
Blood Pressure
Blood Glucose
Activity
Fall Detection
106
107
108
109
105
Alerts Critical Data Corrective Action
120A
120
120B