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MULTI-MODAL SLEEP SYSTEM

Abstract

Systems and methods are provided for a multi-modal sleep system comprising a data processor for operating in a plurality of operating modes. The data processor may detect at least one sensor providing data to the data processor and determine a sensor type associated with each of the at least one sensor. The data processor may select a mode of operation based on the determined sensor type of the detected at least one sensor and of each of the at least one sensor. A first of the plurality of operating modes may be selected in response to determining that the at least one detected sensor includes a first sensor type or combination of sensor types. The data processor may be configured to receive data from the at least one detected sensor and process the received data according to the selected mode of operation to output a characterization of a user's sleep.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/865,820, filed Jul. 15, 2022, which is a continuation of U.S. patent application Ser. No. 17/152,263, filed Jan. 19, 2021, which is a continuation of U.S. patent application Ser. No. 14/497,845, filed Sep. 26, 2014, which is a continuation of U.S. patent application Ser. No. 13/226,121, filed Sep. 6, 2011, now U.S. Pat. No. 8,870,764, the disclosures of all of which are incorporated herein by reference.

FIELD OF THE INVENTION
[0002] This application relates to a multi-modal sleep system operable in one of several modes.
BACKGROUND OF THE INVENTION
[0003] There are various sleep devices in the market today. Some sleep devices are used in sleep labs for diagnosing sleep-related illnesses or conditions. In those applications, the sleep devices employ wet electrodes for detecting signals such as EEG (Electroencephalography), EMG (Electromyography), and EOG (Electrooculargraph), signals of a user for diagnostics. The application of wet electrodes to skin generally requires a conductive gel on the electrode to secure the attachment of the electrode to skin. These wet electrode based systems are thought to be uncomfortable and not suitable for home use, despite the fact that some wet electrodes provide better EEG signal recordings than certain other competing electrodes. In the consumer market, there are now take-home sleep devices that allow a user to monitor and/or track sleep at home. Many of these take-home sleep devices utilize accelerometers to track the physical movements of a user while asleep, e.g., the tossing and turning experienced by the user. Also available now in the consumer market is a sleep tracking device offered by Zeo Inc., which employs dry electrodes, as opposed to wet electrodes, for sensing EEG signals of a user while asleep. The application of dry electrodes to a user's skin requires a headband to secure the dry electrodes to skin.
[0004] However, the above-described sleep devices are single mode devices as each device relies on a single mechanism for receiving input signals (e.g., wet electrode, accelerometer, or dry electrode). Additionally, users prefer more choices in terms of the different ways of wearing or using a sleep device. For example, a user may prefer wearing a headband on some nights and a wristband on other nights. These single-mode devices in the market today limit a user to only one form of use (e.g., wearing a wristband, wearing a headband, etc.). While some sleep analysis devices include multiple sensor modalities, for example a combination of EEG electrodes and an accelerometer, such devices are not capable of determining which sensor modalities are actually outputting usable data and adjusting their operation accordingly. Thus, there exists a first need in the art for a multi-modal sleep device capable of adjusting its mode of operating based on a determination of which of a plurality of sensors is outputting useful data, thereby providing users flexibility in the way in which they use the device.

BRIEF SUMMARY OF THE INVENTION

[0005] In one aspect, systems and methods are provided for a multi-modal sleep system comprising a data processor. In some embodiments, the data processor is configured to operate in a plurality of operating modes. The data processor may detect at least one sensor providing data to the data processor and determine a sensor type associated with each of the at least one sensor. The data processor may select a mode of operation based on the determined sensor type of the detected at least one sensor. A first of the plurality of operating modes may be selected in response to determining that the at least one detected sensor includes a first sensor type or combination of sensor types. A second of the plurality of operating modes may be selected in response to determining that the at least one detected sensor includes a second sensor type or combination of sensor types. The data processor may be configured to receive data from the at least one detected sensor. The data processor may process the received data according to the selected mode of operation to output a characterization of a user's sleep.

[0006] In certain embodiments, the data processor is configured to select the first of the plurality of operating modes in response to detecting a single sensor including an accelerometer. The data processor may be configured to select the second of the plurality of operating modes in response to detecting a single sensor including an EEG electrode. In other embodiments, the data processor is configured to select the first of the plurality of operating modes in response to the data processor detecting a single sensor including an accelerometer.

[0007] The data processor may be configured to select the second of the plurality of operating modes in response to the data processor detecting at least two sensors including an accelerometer and at least a sensor of a second sensor type. The second sensor type may comprise a wet EEG electrode or a dry EEG electrode. The second of the plurality of operating modes may comprise an operating mode that collectively processes data output by the accelerometer and the at least one sensor of a second sensor type. The second of the plurality of operating modes may process data output by the accelerometer to weight a sleep condition analysis otherwise executed on data output by the sensor of the second type.

[0008] The data processor may be configured to select the first of the plurality of operating modes in response to the data processor detecting a sensor including a dry EEG electrode. The data processor may be configured to select the second of the plurality of operating modes in response to the data processor detecting a sensor including a wet EEG electrode.

[0009] In some embodiments, the multi-modal sleep monitoring system includes a built-in accelerometer. The condition of the user's sleep output by the data processor may indicate whether the user is awake or asleep based on data output by the accelerometer.

[0010] In certain embodiments, the multi-modal sleep monitoring system comprises a removable adapter for coupling the data processor to a sensor of a first type. In other embodiments, the data processor may be configured to couple directly to a sensor of a second type without the adapter.

[0011] The multi-modal sleep monitoring system may comprise a remote computing device configured for wireless communication with the data processor for receiving data indicative of the output sleep condition. The remote computing device may be configured for presenting sleep condition data based on the data received from the data processor.

[0012] According to another aspect, the invention relates to a method of for operating a multi-modal sleep monitoring system in a plurality of modes. The method includes a data processor detecting at least one sensor providing data to the data processor and determining a sensor type associated with each of the at least one sensor. The data processor then selects a mode of operation based on the determined sensor type of the detected at least one sensor and of each of the at least one sensor. A first of the plurality of operating modes may be selected in response to determining that the at least one detected sensor includes a first sensor type or combination of sensor types. A second of the plurality of operating modes may be selected in response to determining that the at least one detected sensor includes a second sensor type or combination of sensor types. The data processor then receives data from the at least one detected sensor and processes the received data according to the selected mode of operation to output a characterization of a user's sleep.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing and other objects and advantages of the invention will be appreciated more fully from the following further description thereof, with reference to the accompanying drawings wherein:

[0014] FIG. **1** depicts a multi-modal sleep system, according to an illustrative embodiment of the invention;

[0015] FIG. **2** depicts the multi-modal sleep system of FIG. **1** operating in a first mode of operation, according to an illustrative embodiment of the invention;

[0016] FIG. **3** depicts the multi-modal sleep system of FIG. **1** operating in a second mode of operation, according to an illustrative embodiment of the invention;

[0017] FIG. **4** depicts the multi-modal sleep system of FIG. **1** operating in a third mode of operation, according to an illustrative embodiment of the invention; and

[0018] FIG. **5** is a flow chart of a method of determining a mode of operation of the multi-modal sleep system, according to an illustrative embodiment of the invention.

DETAILED DESCRIPTION

[0019] To provide an overall understanding of the invention, certain illustrative embodiments will now be described. However, it will be understood by one of ordinary skill in the art that the systems and methods described herein may be adapted and modified as is appropriate for the application being addressed and that the systems and methods described herein may be employed in other suitable applications, and that such other additions and modifications will not depart from the scope thereof.

[0020] FIG. **1** depicts a multi-model sleep system **100**, according to an illustrative embodiment of the invention. The multi-model sleep system **100** includes three modes of operation. In each mode, the system **100** includes a processing component **110** and a user interface device (such as a sleep base station **120** and a mobile device **122**). The three modes of operation include a first mode of operation **102**, a second mode of operation **104**, and a third mode of operation **106**.

[0021] In the first mode **102**, the system **100** operates using a built-in accelerometer and flexible dry conductive electrodes or wet electrodes designed to be in contact with the skin of a user in the forehead region. In the second mode **104**, the system **100** operates using a built-in accelerometer and wet or dry conductive electrodes also made to be in direct contact with the skin of a user in the forehead region. In the third mode **106**, the system **100** uses only a built-in accelerometer for detecting physical movements of a user while asleep. In the third mode **106**, the system **100** may be secured onto the wrist. Details of how the sleep system **100** is configured and operates in each of the three illustrative modes of operation are described in relation to FIGS. **2**-**4**.

[0022] In operation, the processing component **110** receives either a raw electrical signal from the electrodes signals or movement data, or both, depending on the mode of operation. The raw electrical signal includes information indicative of one or more of EEG, muscle tone, eye movement and galvanic skin response. The processing component **110** then processes the received data, also based on the mode of operation. Based on the received data monitored during a night of sleep, the processing component **110** determines the various sleep stages that the user experienced and the duration associated with each stage. In one embodiment, sleep is classified according to the R&K standard (defined in 1968 Allan Rechtschaffen and Anthony Kales), which includes sleep stages 1, 2, 3, 4, and REM sleep as well as an awake stage. Alternatively sleep stages may be defined according to other standards, such as the standard specified by the American Academy of

Sleep Medicine, which includes wake, N1, N2, N3, and REM sleep stages. In yet another alternative, the processing component **110** classifies a user's sleep into one of wake, REM, light, and deep sleep stages. The determination of sleep stages may be based on an analysis of the electrical signal received through the electrodes by itself or in conjunction with data out put by the accelerometer. In certain embodiments, other sensor modalities are incorporated into the sleep stage classification analysis in addition or in the alternative to the EEG and acceleration data. For example, in one embodiment, in addition or in the alternative to the processing component **110** including wet or dry electrodes, the processing component includes a LED/photodiode pair for generating a photoplethysmogrphic signal. This signal can be used to determine heart rate, heart rate variability, and respiration rate, one or more of which is then processed to determine sleep stages of a user.

[0023] In some embodiments, the processing component **110** performs various signal processing operations on the received signal, such as to increase the signal to noise ratio (SNR), to compute a mathematical transform of the signal for further data manipulation and information extraction, and to amplify the raw input signal. In some embodiments, processing component **110** is stored with instructions corresponding to different sets of data analysis methods for the different modes of operations. In particular, as described in relation to FIG. **2**, the combination of an EEG signal and movement data indicative of a user's physical movements while asleep require a special set of analysis.

[0024] In some implementations, after the raw input signal is processed, the processing component **110** wirelessly communicates the processed data to the base station **120** or the mobile device **122**. In addition to communicating wirelessly, the base station **120** and/or the mobile device **122** can be physically connected to the processing component **110** via various mechanisms. For example, the base station **120** and/or the mobile device **122** may include adapters, such as an electrically conductive holder, to enable a direct electrical contact between the processing component **110** and the base station **120** and/or the mobile device **122**. In some embodiments, the processing component **110** may include an SD card, mini-SD card, micro-SD card or other suitable removable integrated circuit memory device for storing the processed data. The removable memory device can then be removed from the processing device and directly inserted into various devices, such as the base station **120**, the mobile device **122**, a computer, a tablet, a television, and/or any other type of device with processing and/or storage capabilities. Alternatively, or additionally, the processing component **110** can wirelessly communicate with one of the above-mentioned devices according, for example, to the BLUETOOTH, ZIGBEE, or WIFI protocols. In yet another embodiment, the data received from the processing component **110** can be forwarded to a remote server via a wired or wireless Internet connection. In some embodiments, the receiving device can perform post-processing on data collected and/or determined by the processing component **110**.

[0025] In some embodiments, the base station **120** and the mobile device **122** depict the data processed by the processing component **110** in a user-readable format to a user. For example, the various sleep stages and the duration of each may be presented to the user via the base station **120** or the mobile device **122**. The sleep stages may be plotted on a time-scale and displayed to the user on a screen of the base station **120** or via an application on the mobile device **122**. In some implementations, the base station **120** or an application installed on the mobile device **122** can carry out a portion of the analysis of the raw input signal for the processing component **110**. In other implementations, the processing component **110** offloads the entire data analysis process to the base station **120** or an application on the mobile device **122**. In particular, the various data processing or analysis techniques described in co-pending U.S. patent application Ser. No. 11/586,196 ("'196 application") may be used in the wet electrode system **104** and are suitable to be used in conjunction with the processing of movement data generated by the accelerometer when both electrodes and accelerometer are used. The entirety of the '196 application is incorporated herein by reference.

[0026] In some embodiments, the base station **120** and/or the mobile device **122** are connected to the internet. Each user of the system **100** may be given a web account allowing the user to store the sleep data in a remote location accessible by a web server. The stored data may further be processed or analyzed by any tools provided to the user by a web application associated with the user account. Examples of such web based tools or applications are described in relation to co-pending U.S. patent application Ser. No. 12/387,730, the entirety of which is incorporated herein by reference.

[0027] FIG. **2** depicts the multi-modal sleep system **100** of FIG. **1** operating in a first mode of operation **102**, according to an illustrative embodiment of the invention. In the first mode **102**, the multi-modal sleep system **100** includes a headband **202**, dry electrodes **204**, and the processing component **110**, which has an accelerometer. In some embodiments, the headband **202**, dry electrodes **204**, and processing component **110** are modular and may be assembled according to the diagram illustrated in FIG. **2**. In the illustrative embodiment depicted in FIG. **2**, the dry electrodes **204** couple to the processing component **110** via three conductive mechanical fasteners. The male portions **206** of the mechanical fasteners extend from the dry electrodes, with corresponding female portions **208** of the fasteners built into the rear-facing side of the processing component **110**. In operation, the processing component **110** receives and processes both the EEG signal sensed by the dry electrodes **204** as well as the movement data generated by the accelerometer.

[0028] In some embodiments, the processing of the EEG signal and the movement data are separate and modular. In other embodiments, the processing of the two sets of data is intertwined in that one set of data may be used to adjust the other set. For example, the movement data may be fed as input to the processing of the EEG signal, or vice versa. For instance, the processing component **110** may determine that a user is in REM sleep from 2 a.m. to 5 a.m. based on the EEG signal received during that time period. The movement data collected during the same time period may indicate a higher confidence in this assessment if the movement data indicates less tossing and turning during the same time period. Alternatively, the movement data may indicate a lower confidence in the assessment determined based on the processing of the EEG signal. In certain embodiments, the movement data may be interjected into the processing of the EEG signal before an assessment or a conclusion based on the EEG signal is determined.

[0029] In one particular example, the processing component **110** includes a neural network that outputs for each sleep time interval a score indicative of the likelihood that the user is in each stage of sleep the processing component **110** considers. The processing component then classifies the sleep time interval the sleep stage having the highest score. In one implementation, initial scores are calculated solely based on EEG data. Then, based on movement data obtained from the accelerometer, one or more of the scores may be increased or decreased prior to a final classification of the sleep time interval. For example, if the processing component detects relatively frequent movements during a time interval, the scores for the light sleep and/or wake stages may be increased or the scores for deep and/or REM sleep may be decreased. In alternative implementations, acceleration day may be used to alter the initial scoring algorithm.

[0030] Details of how an EEG signal detected by dry electrodes may be processed to determine sleep data, e.g., sleep stages, are further described in co-pending U.S. patent application Ser. No. 11/586,196, the entirety of which is incorporated herein by reference. An additional example of an EEG-based sleep staging algorithm suitable for use with the above-described system includes the algorithm disclosed in "Automatic Sleep Stage Scoring System Using Genetic Algorithms and Neural Network," Engineering in Medicient and Biology Society, 2000, Proceedings of the 22.sup.nd Annual Internation Coverence of the IEEE, 2000. Details of how an EEG signal detected by dry, wet, or any other forms of electrodes may be processed in conjunction with movement data as detected by an accelerometer are discussed below in relation to FIG. **4**.

[0031] FIG. **3** depicts the multi-modal sleep system **100** of FIG. **1** operating in a second mode of operation **104**, according to an illustrative embodiment of the invention. In the second mode **104**, the multi-modal sleep system **100** includes wet electrodes **302**, an adapter **304**, and a processing component **110**. The processing methods used in connection with the wet electrodes conform substantially to the processing methods used in connection with the dry electrodes as described above.

[0032] The wet electrodes **302** may include any wet electrodes. The wet electrodes **302** may be applied directly to the skin near the forehead region of a user if direct contact can be made between the wet electrodes **302** and skin. The application of the wet electrodes **302** may include the use of gel, adhesives, or any other forms of attachment. In some embodiments, to further support the attachment of the wet electrodes **302** to skin, the headband **202** is used to strap the wet electrodes **302** around one's head. The wet electrodes **302** may have a differential pair of electrodes or any number of electrodes being placed in variable distance from each other, as long as the distance is suitable for measuring EEG signals.

[0033] In the illustrative embodiment depicted in FIG. **3**, the adapter **304** is used to ensure that the same processing component **110** can process sleep sensor data collected from either types of electrodes (i.e., to work with both the dry electrodes **202** and the wet electrodes **302**, even if they have different electrodes placement or arrangement). To that end, the adapter includes mechanical fasteners on both its rear-facing and front facing surfaces. The rear-facing surface of the adapter includes female portions of mechanical fasteners corresponding to male portions extending from the front-facing surface of the wet electrodes. The front-facing surface of the adapter includes male portions of mechanical fasteners positioned to snap into the female portions of the mechanical fasteners built into the rear surface of the processing component **110**. The adapter **304** includes conducting material, such as thin wires or bus lines, connecting the female fastener portions on its rear side to the male fastener portions on its front side. Preferably, all of the mechanical fasteners are conductive and made of a material suitable for conducting EEG signals without introducing and undesirable amount or noise or overly attenuating the signals.

[0034] Providing a user with the flexibility to select the desired wearing mode is advantageous. For example, while wet electrodes provide more accurate EEG recordings than dry electrodes and are more likely to stay on, dry electrodes are reusable and some users find them to be more comfortable to wear. Thus, a user may wish to use the dry electrodes on some nights. However, on other nights, the user may decide to use an eye mask, which may conflict with the use of the headband for the dry electrodes. Thus, the user might prefer a wet electrode system that simply attaches itself to the user either on the forehead or other parts of the user's head or elsewhere where the wet electrodes can detect an EEG signal.

[0035] FIG. **4** depicts the multi-modal sleep system **100** of FIG. **1** operating in the third mode of operation **106**, according to an illustrative embodiment of the invention. In this mode of operation, the system **100** only requires use of the processing component **110** and a wristband **402**. The wristband **402** includes a pouch **404** for housing the processing component **110**. In an alternative implementation, the wristband **402** includes male mechanical fastener portions for snapping into female mechanical fastener portions built into the rear surface of the processing component **110**. The male mechanical fastener portions can, but need not, be conductive, as they are merely included for securely holding the processing component **110** in place.

[0036] As indicated above, in alternative embodiments, the processing component may take galvanic skin response at the user's wrist into account in its sleep stage processing. In such embodiments, suitable electrodes can be built into the wristband **402** and the male mechanical fastener portions would be constructed of or coated with a conductive material to convey the detected signals to the processing component **110** for analysis. In alternative embodiments of the processing component **110** that include a LED/photodiode pair, a photoplethysmographic signal may be generated by illuminating and measuring the light reflected from the wrist. This signal can then be processed to determine heart rate, heart rate variability and/or respiration rate, one or more of which is incorporated into the sleep staging algorithm.

[0037] In accelerometer only mode of operation depicted in FIG. **4**, the system **100** utilizes a built-in accelerometer of the processing component **110** for measuring the physical movements of a user while asleep. In some embodiments, the user wears the wristband **402** with the processing component **110** around his/her wrist. In other embodiments, the wristband **402** is adjustable so that the user can wear the processing components **110** on or around any parts of his/her body, such as the ankle, legs, neck, waste, and arms. In certain embodiments, the movements of a user while asleep can also be detected by placing the processing components **110** in or under one's pillow or on other parts of one's bed.

[0038] In some implementations, the processing component **110** comprises a 3-axis (or triaxial) accelerometer capable of measuring the x-y-z angle tilts relative to the gravity vector. In other embodiments, the processing component **110** comprises one or more single or dual-axial accelerometers, instead of a single triaxial accelerometer. For example, an x/y-axis accelerometer may be used with a z-axis accelerometer.

[0039] In operation, as a user wearing the processing component **110** having the accelerometer moves, forces are exerted on a crystal in the accelerometer by a free-floating mass. Three crystals are needed to detect any force exerted by the free-floating mass in all three directions (x-y-z). Based on the exerted force, which is a vector with direction and magnitude, information about the direction and magnitude of a user's physical movement can be directly inferred to generate movement data. In some implementations, the hysteresis of an accelerometer is factored into the calculation of the movement data. With the movement data, the processing component **110** can track the physical movements of a user while asleep, such as tossing and turning. Based on the movement data, the processing component **110** can determine whether the user is awake or asleep, which may be indicated by the amount of detected movement exceeding a pre-determined threshold amount. Various types of algorithms may be used to process movement data collected by an accelerometer, such as the algorithms identified in “Comparing Different Methodologies Used in Wrist Actigraphy”, by Stephen W. and Jennifer R. Spiro, Sleep Review, Summer 2001, available at http://www.sleepreviewmag.com/issues/articles/2001-07.sub.—04.asp. The movement data is then processed and plotted in a user-friendly and readable format to a user on an interface device, such as the base station **120** or mobile device **122** as described above. Quality of sleep may also be estimated based on the movement data. In some embodiments, the movement data may be tracked and stored so that an animation of the physical movements experienced by a user is depicted to the user.

[0040] In one particular embodiment, the movement data is analyzed to determine an activity value for a series of pre-determined time periods, such as every 30 seconds, to determine the extent of the user's movement moved during the pre-determined time period. Preferably, the time periods range from approximately 2 seconds up to about 1 minute. Preferably, the movement period is synchronized with a sleep stage analysis period. The activity value moved may be inferred from or indicated by the change in the movement vector as determined by the built-in accelerometer. For example, the processing component may sample the movement data at various sampling rates, such as 50 Hz, depending on the sensitivity of the built-in accelerometer (e.g., higher sensitivity may require a lower sampling rate). Each directional component of a movement vector (e.g., x component, y component, and z component) at a sampled time period is digitally filtered with a filter having pre-determined filter lengths (i.e., number of samples included in the filter) and coefficients. Test data may be gathered to experimentally determine optimal filter coefficients and filter lengths for each vector component of a movement vector based on the specific accelerometer used. Suitable filters include bandpass filters having frequency ranges from less than 1.0 Hz (e.g., 0.5 or 0.025 Hz) up to about 10 or 11 Hz. In some embodiments, the activity value during a pre-determined time period is determined based on an integration of magnitudes of filtered movement vectors with respect to time. In other embodiments, activity values are derived based on a number of zero-crossings in the accelerometer data. In still another embodiment, the activity value is based on an amount of time that the accelerometer output exceeds a threshold value. The activity value for a specified period of time is then compared to a threshold value. In the case that an activity value for a time period exceeds the threshold value, the user is determined to have made substantial movement during that period. The threshold value may be gathered from experimental test data and may differ depending on the gender, age, historical sleep data, or other type of user information. Various additional processing techniques can be applied to the activity value determination process. For example, movement data collected from adjacent time periods (e.g., from 0 to 30 seconds and 31-60 seconds) may be processed collectively to smooth out the transition point between two adjacent time periods or time windows (e.g., between 30 second and 31 second).

[0041] In some embodiments in which the user is wearing the processing component in a predetermined orientation (e.g., attached to the headband on the user's forehead), the processing component **110** has an algorithm that determines whether a user is in a vertical position, such as sitting down or standing up. This may be determined based on the magnitude of the accelerometer output associated with the longitudinal axis of the body. If the user is lying down, the accelerometer should detect little acceleration in this direction. If the user is vertical, the accelerometer output will reflect the force of gravity. being sitting or standing. If the processing component detects a vertical user orientation, the processing component **110** either determines that the user is awake or introduces a strong presumption that the user is awake—strong EEG data to the contrary may suggest sleep walking. As described above, this can be accomplished by using the vertical user determination as an input to the sleep stage determination algorithm, thereby heavily weighting the algorithm towards outputting a sleep stage of “awake”.

[0042] In alternative embodiments, the processing component is configured to identify occurrences of a user sleeping in various positions. For example, accelerometer data can be analyzed to determine if the user is sleeping on their back versus their side or stomach by determining the orientation and/or movement of their head.

[0043] FIG. **5** is a flow chart of a method **500** of determining a mode of operation of the multi-modal sleep system, according to an illustrative embodiment of the invention. The method **500** begins with receiving sensor data (step **502**) by the dry electrodes **202**, wet electrodes **302**, and/or an accelerometer. With the received sensor data, including EEG and/or movement data, the processing component **110** first determines sensor modalities before it begins analyzing the sensor data to extract sleep information from the data (step **504**). In one embodiment, the processing component **110** makes such a determination based on a user indication of the mode of operation. In one such embodiment, the processing component **110** is built to include one or more buttons, switches, or other simple mechanical user input mechanisms for allowing a user to indicate whether the user is going to use only the accelerometer in the processing component **110**, wet electrodes, or dry electrodes, or a combination of one or more types of sleep sensors. In another embodiment, a user may indicate the selected modality for the sleep session using a software application or other user interface element on the base station **120** or mobile device **122**.

[0044] In an alternative embodiment, the processing component **110** makes a modality determination without any user input. For example, the processing component **110** measures the impedance of the signal received at the mechanical fasteners built into the processing component **110**. In one embodiment, the processing component **110** stores a single impedance threshold value. If the input impedance **110** exceeds the threshold, for example a threshold value representative of infinite impedance, the processing **110** component determines that it is not connected to any electrodes, and thus operates solely using accelerometer data. If the processing component **110** detects a lower impedance, the processing component **110** determines that electrodes are connected and processes data obtained via the electrodes as well output by the accelerometer. In this embodiment, no distinction is made between data output by wet electrodes versus dry electrodes.

[0045] In other embodiments, the processing component **110** stores multiple impedance values, one corresponding to each sensor type that might be coupled to the processing component **110**, and one value representing an infinite impedance. In this embodiment, the processing component **110** processing received sensor data differently depending on the specific type of sensor detected. For example, the processing component **110** may store one or more configuration parameters associated with each impedance value which is then used to process the received sensor data. Alternatively, the processing component **110** executes different processing algorithms based on the type of sensor detected.

[0046] In some embodiments, the processing component **110** includes additional sensing circuitry for sending test signals to electrodes to obtain a read-out of the input impedance. For example, a small electrical pulse may be generated and sent to the skin of a user via one electrode and measured at a second electrode. The measurement is then used to calculate input impedance of the skin according to Ohm's law.

[0047] Noise in an input signal is another parameter that may be used to determine sensor modality. Wet electrodes are less susceptible to noise than dry electrodes. The processing component **110** determines the noise levels in the signal or the Signal to Noise Ratio (SNR) of the signal and compares both the noise frequency (such as the 60 Hz power line noise) and amplitude with pre-stored threshold values to determine whether the user is wearing the dry or wet electrodes.

[0048] Testing data may be gathered on the usage of wet electrodes and dry electrodes to create signal profiles for both electrodes. A signal profile contains information idiosyncratic to a particular type of electrode and may be stored in the memory of the processing component **110**. With the stored signal profile, the processing component **110** first generates a signal profile of an input signal and then compares the generated signal profile with the stored signal profiles to determine which one of the two types of electrodes is currently being used by the user. In some embodiments, signal profiles of different sleep stages may be experimentally collected and compared to actual signal profiles generated for the EEG signals detected while a user is asleep. The comparison between the signal profiles of different sleep stages and the actual EEG signal profile of a user enables the processing component **110** to better process the received input signal to more precisely determine sleep states, such as sleep stages that a user may have experienced and any duration associated therewith.

[0049] Once the sensor modality is determined, the processing component **110** invokes the appropriate processing method or algorithm for processing the received input signal at step **506** (i.e., an EEG signal, movement data, or a combination of both). Each type of sleep sensor or each combination of sleep sensors, such as wet electrodes, dry electrodes, or an accelerometer, may be associated with its particular processing method or algorithm dedicated to the analysis of data collected by the sleep sensor(s).

[0050] The foregoing embodiments are merely examples of various configurations of components of dry electrode systems described and disclosed herein and are not to be understood as limiting in any way. Additional configurations can be readily deduced from the foregoing, including combinations thereof, and such configurations and continuations are included within the scope of the invention. Variations, modifications, and other implementations of what is described may be employed without departing from the spirit and the scope of the invention. More specifically, any of the method, system and device features described above or incorporated by reference may be combined with any other suitable method, system, or device features disclosed herein or incorporated by reference, and is within the scope of the contemplated inventions.

Claims

1. A multi-modal sleep monitoring system for sleep data collection of a person's sleep for characterizing sleep and awake states, comprising: a data processor, in a housing, the data processor configured for operating in a plurality of operating modes using a plurality of sensors, the data processor configured to: detect at least one sensor of the plurality of sensors; determine a sensor type associated with the at least one sensor and a signal quality of a signal from the at least one sensor and select a mode of operation based on the determined sensor type of the detected at least one sensor and the determined signal quality of the at least one sensor; receive data from the at least one detected sensor; and process the received data according to the selected mode of operation to output a characterization for assessing the person's sleep, wherein the data processor is configured to operate in the selected mode of the plurality of operating modes; wherein the data processor is configured to receive signals from the plurality of sensors, the plurality of sensors comprising mountable sensors configured to be mounted on the person, the plurality of sensors comprising a photoplethysmography sensor and a built-in three-axis accelerometer to generate signals indicative of physical movement of a body of the person; a software application configured to control (a) generation of a user interface on a computing device external to the housing, the user interface configured to enable a user to make an indication to the data processor of a selection of a sensor modality; and (b) communicate with the data processor to cause configuration of the data processor to operate according to the indication of the selected sensor modality; and web server apparatus connected to a network, the web server apparatus comprising a plurality of user accounts, wherein a user account of the plurality of user accounts is configured for receiving and evaluating data recorded by the data processor on a memory card, the recorded data comprising at least a characteristic of respiration and heart rate.

2. The multi-modal sleep monitoring system of claim 1, wherein the data processor is configured to receive a raw electrical signal from electrodes and movement data.

3. The multi-modal sleep monitoring system of claim 2, wherein the raw electrical signal includes information indicative of one or more of EEG, muscle tone, eye movement and galvanic skin response.

4. The multi-modal sleep monitoring system of claim 1, wherein the system is further configured to generate a sleep quality estimate based on movement data tracked with the data processor.

5. The multi-modal sleep monitoring system of claim 1 wherein the system is configured to depict physical movements experienced by a user from stored movement data.

6. The multi-modal sleep monitoring system of claim 1 wherein an application for a mobile device configures the mobile device to carry out at least a portion of an analysis of an electrical signal from electrodes of the system.

7. The multi-modal sleep monitoring system of claim 6 wherein the data processor is further configured to wirelessly communicate with the mobile device.

8. The multi-modal sleep monitoring system of claim 7 wherein mobile device is configured to present to a user with determined one or more sleep stages and/or duration of determined one or more sleep stages.

9. The multi-modal sleep monitoring system of claim 1 further comprising a base station configured to communicate with the data processor, wherein the base station is configured to carry out at least a portion of an analysis of an electrical signal from electrodes of the system.

10. The multi-modal sleep monitoring system of claim 9 wherein base station is configured to present to a user, determined one or more sleep stages and/or duration of determined one or more sleep stages.

11. The multi-modal sleep monitoring system of claim 1 wherein the data processor is configured with an LED/photodiode pair for generating a photoplethysmographic signal.

12. The multi-modal sleep monitoring system of claim 11, wherein the system is configured to determine heart rate, heart rate variability and/or respiration rate from the photoplethysmographic signal, and determine one or more sleep stages based on one or more of the heart rate, heart rate variability and/or respiration rate.

13. The multi-modal sleep monitoring system of claim 1, wherein the data processor is further configured to forward received data to the web server apparatus via a wired or wireless communications connection.

14. The multi-modal sleep monitoring system of claim 1, wherein the data processor is configured with separate processing modules for each of (a) an electrical signal from electrodes, and (b) movement data output by the accelerometer.

15. The multi-modal sleep monitoring system of claim 1, wherein the data processor is configured with an intertwined processing module for (a) a first data set from an electrical signal from electrodes, and (b) a second data set of movement data output by the accelerometer, wherein the intertwined processing module uses one of the first data set and the second data set to adjust the other one of the first data set and the second data set.

16. The multi-modal sleep monitoring system of claim 1, wherein a mode of the plurality of operating modes operates to process data output by the accelerometer to weight a sleep condition analysis otherwise executed on data output by a sensor of a different type from the accelerometer.