ABSTRACT

A method and system is invented for continuous monitoring, real-time analysis, and automated and personalized training of exercise. The system embodies a multi-sensor data acquisition system to measure body sounds, body signs, vital signs, motions, and machine settings continuously and automatically. The system is able to capture the body sounds and other vital signs, analyze them, and report and display summarized results. The signal processing functions utilize a unique signal separation and noise removal methodology by which authentic signals can be extracted from interfered signals and in noisy environments, even when signals and noises have similar frequency components or are statistically dependent.

The method and system will facilitate continuous monitoring, real-time analysis, and computerized evaluation of level of effort, physical stress, and resulting fatigue during physical activity or exercise. In addition, based on body sound data, or in combination with other monitored physiological signals, and knowledge of the individual and exercise being performed, the system will evaluate the person's physical performance and then act as an automated coach to guide exercise intensity and duration thereby optimizing and individualizing the training process. The invention is especially targeted, but not limited to, cardiopulmonary monitoring for athletes for improving the efficiency and safety of exercise, rehabilitation programs for out-of-shape individuals, and routine exercise of the general population.
Figure 1
Figure 2a
Figures 3a, 3b, 3c
Figure 4
Figure 5
Figure 6

Training Machine Database

PEMT PDA

BEGIN

Select Machine

Cardio

Machine Type?

Strength

Capture Unique ID #

Determine Values for Ergonomic Settings

More Settings?

NO

YES

For Each Setting Type:
Time
Resistance
Distance
RPM / Speed
Incline

Select Values

Save Cardio Data

Name & Save Workout & Schedule in Personal Fitness DB

Save Strength Data

Personal Fitness Database

END
Athlete Connects PEMT PDA to:
1. PEMT Server
2. Personal PC

Upload Completed Workout Results

Merge Results into Personal Fitness Database

Graph progress:
1. Performance
2. Fitness
3. Calorie Burn

Personal Trainer?

PEMT Coach Module Makes Recommendations Based on Data in Graphs

Send Progress Report to Personal Trainer
PT makes new Recommendations

Save Adjusted Workout & Schedule in Personal Fitness DB

END
Figure 10
Athlete establishes PEMT PDA Communications with PEMT Class Trainer Server

PEMT sends Athlete ID # or Athlete Demographics & Fitness Info to PEMT CTS

Trainer gives Class Exercise Instructions

PEMT PDA sends Vital Sign Data to PEMT CTS

PEMT CTS Combines All Athlete Data:
1. Checks Individual Safety
2. Checks Individual Progress
3. Summarizes Group Results
4. Displays Group Results

Trainer Studies Individual & Group Results Summaries

Individual

Meeting Goals?

No

Yes

Trainer: 1. looks for medical problems 2. gives encouragement 3. makes easier modifications

Class or individual?

Meeting Goals?

No

Yes

Trainer: 1. looks for medical problems 2. gives praise

Trainer makes Class Loss Difficult
Ex. Decreases RPM/IMPH
Decreases Level Settings

Trainer makes Class More Challenging
Ex. Increases RPM/IMPH
Increases Level Settings

Class Over?

No

Yes

END

Figure 11
BEGIN

PEMT Class Trainer Servers establish communication with Class Contest Server or Contest Website

Trainer registers class for contest level and students

Class Contest Server:
1. Matches registrants
2. Publishes rules
3. Initiates contest

Class Trainer Servers send summary progress data to Class Contest Server

Class Contest Server combines results and sends current standings to Class Servers

Contest Over?

Class Contest Server:
1. Analyzes final results
2. Decides contest winners individual and group
3. Makes awards
4. Publish summaries

END

Figure 12
BEGIN

- Filtering Off-Band Noise

ANC Independent Noise Removal

- Time-Shared Noise Cancellation

Signal Separation Cyclic System Reconfiguration Method

Adaptive Individualized Pattern Recognition

Real-Time Individualized Optimal Diagnosis

END

Figure 13
Figures 14a, 14b, 14c
METHOD AND SYSTEM FOR CONTINUOUS MONITORING AND TRAINING OF EXERCISE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/783,424 filed on Mar. 17, 2006. The disclosure of the above application is incorporated herein by reference.

FIELD

[0002] This disclosure relates to methods and systems for facilitating continuous monitoring, real-time analysis, and computerized evaluation of level of effort, physical stress, resulting fatigue, and remaining energy reserves during physical activity or exercise and then performing evaluation of that person’s physical performance and acting as an automated coach to guide exercise intensity and duration thereby optimizing and individualizing the training process. It also makes possible more efficient coaching and training of groups.

BACKGROUND

[0003] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

Continuous Monitoring of Exercise

[0004] Currently, heart rate is primarily used as an indicator of exercise intensity in many settings and situations by individuals performing exercise. These active individuals typically use heart rate monitors that are built into either wrist watch type devices or into cardiac training equipment such as treadmills, recumbent bicycles and elliptical trainers, among others. However, the utility of conventional exercise monitors is limited to simple calculation of the heart rate, virtual distance moved, and sometimes calorie expenditure rather than objective level of effort, or actual measures of fatigue, stress and remaining capacity for activity.

Body Sounds and Body Signs for Exercise Monitors

[0005] Continuous monitoring of body functions can be of essential importance in evaluation of athletes for optimal pulmonary and cardiac training and for detection of dangerous conditions during physical activity before they become critical. Typical body sounds include heart sounds, lung sounds, upper airway respiratory sounds, etc. Other body signs such as chest movements contain further physiological information. These body sounds and signs contain specific information that is related to exercise. For example, some essential parameters can be derived from body sounds: heart rate, heart pumping volume, respiratory rate, inhale/exhale durations and volume, among others. Also, chest movements can be used to derive respiratory volumes. All these physiological parameters as well as others can be used jointly to measure a person’s levels of effort, stress, fatigue and fitness.

[0006] For instance, it is well perceived and commonly used that the heart rate is useful for assessing activity levels. Also, it is known that heart rate variability indicates a person’s effort and mental stress. Combined parameters, such as inspiration duration vs. the overall respiratory rate can be effectively used to evaluate a person’s level of effort and fatigue. Further, signal analysis of the body sounds, such as Fourier analysis and statistical analysis, can extract features for body activity and exertion. Such features are necessary to accurately estimate total calorie expenditure.

Noise Reduction During Body Sound Acquisition

[0007] To obtain quantitative and reliable monitoring and detection of emergency situations, it is especially important that body sound acquisition obtains sounds of high clarity. But acoustic environments of gymnasiums and other related sports type facilities impose great challenges for body sound acquisition. Unlike acoustic labs in which noise levels can be artificially controlled and reduced, and body sounds can be processed off-line, these environments are very complex acoustically due to loud music, clanging of weights and vibrations from strength training machines, conversations, audio from televisions, and other real-life aural artifacts. The unpredictable and broadband natures of such noises render these physical training locations very difficult environments for sound analysis.

[0008] The body sound analyzer invention disclosed in U.S. patent application Ser. No. 11/367,807 surmounts the problems inherent in body sound acquisition and analysis and this device and methods can be applied to clinical settings such as might be found in a physical rehabilitation center.

[0009] However, this new system and method can also be used in removing noise from other physiological (such as vital signs), and motion signals (such as chest movements), and applied to non-clinical settings much akin to rehabilitation centers which are essentially exercise studios. Because body sounds and vital signs contain such a rich reservoir of vital physiological information, this type of data can be useful for monitoring a person’s response to physical activity, and can be definitive in determining the amount of effort being exerted by a person participating in strenuous physical exercise.

Separation of Body Sounds During Exercise

[0010] Performance of physical tasks places a tax on the cardiopulmonary systems of the human body. Changes in these physiological systems must be evaluated in order to quantify the person’s physical reaction to exercise. Body sounds and vital signs, such as heart and lung, interact with each other during data acquisition. Exercise introduces even more corruption among body sounds and causes difficulty for capturing authentic body sounds and vital signs, and causing difficulties in subsequent diagnosis. The body sound analyzer invention of U.S. patent application Ser. No. 11/367,807, which the present disclosure builds upon, provides multiple improvements in the ability to separate the overlapping body sounds and remove confounding noise. In the present invention, the body sound analyzer invention will be used in its extension to other signals including vital signs and motion measurements. This technology is highly desirable, specifically for the present invention because it helps to perform computerized cardiopulmonary evaluation during exercise, to use the functionality afforded by the
previously disclosed body sound analyzer disclosure of U.S. patent application Ser. No. 11/367,807.

Pattern Recognition and Evaluation of Exercise Physiology

[0011] Body sounds, vital signs, and motions contain a rich reservoir of vital physiological, pathological, and fitness information that is of critical importance for clinical diagnosis and sports medicine. Continuous monitoring of body sounds, vital signs, and motions therefore could provide a non-invasive and inexpensive means for assisting in evaluating accurately and in real-time the impact of physical activity in terms of level of effort, physical stress, overall fatigue, relation to peak performance, and relative remaining energy reserves with respect to maximum available. Moreover it becomes more feasible to have the information necessary to encourage an exerciser to greater effort in order to meet the levels needed for them to expend sufficient calories to support their weight loss goals. In addition, it is possible that by monitoring heart and lung functions continuously a number of the sudden deaths that occur during exercise might be avoided by use of the exercise monitors disclosed in the present application.

Prior Art in Heart Rate Monitors

[0015] A very large number of products are now available to portably monitor the heart rate. The rationale for their use is: (1) in order to reach fitness goals, exercise must be at the right intensity; (2) heart rate is currently the only accurate measurement of intensity or exertion level; and (3) portable heart rate monitors (HRM) are the easiest and most accurate way to continuously measure heart rate.

[0016] A heart rate monitor (HRM) is a tool used to help set the pace for exercise. If an individual exercises too hard, they will most likely quit the activity before they get the real benefit. By contrast, there are people who exercise at too leisurely a rate and therefore do not realize the benefits of losing weight or enhancing cardiovascular functions. Either too slow or too fast a workout prevents the full benefit of exercise to be gained. Currently, HRM devices can be used to set pace levels during a workout. The claim for these HRM devices is that a user could know that they are getting a similar workout from a treadmill, a weight circuit or jumping rope by measurement of their heart rate alone. The companies that sell these devices and their customers thereby tend to equate heart rate with workout intensity.

[0017] But elite athletes have resting heart rates that would be dangerously low in a normal person. The extreme high levels of heart rate for elite athletes during strenuous exercise would likewise indicate dangerous heart rhythms in a normal person. While a single example, this illustrates that it is not the case that heart rate is a complete measure of exercise impact. It is further clear that heart rate alone does not indicate effort level of the cardiopulmonary system. Therefore a true measure of exertion during exercise must combine more information, such as heart and lung functions and other body signs.

Prior Art in Sports Training

[0012] Historical improvements by athletes in sports performance are attributable to advances in technique and form, but also due to increases in strength, neuromuscular speed, and cardiovascular endurance. Recent improvements in these areas have been assisted by new exercise technologies. The most modern sports training centers are able to use sophisticated physiological monitors identical to the most expensive equipment used by physicians. Migration of training techniques used by professional and elite athletes to the general population has increased understanding that aerobic and anaerobic exercise can be made more efficient by training based on heart rate.

[0013] In order to more accurately measure aerobic capacity, sports doctors measure many physiological variables including lung functions. While pulmonary function is measured for elite athletes it is not currently practical to measure for ordinary athletes unless there are some prevailing medical conditions such as exercise induced asthma. Even when there is the possibility of exercise induced respiratory problems, lung function is still not measured during day-to-day training by professional athletes, much less amateurs.

[0014] Currently, in actual practice, day-to-day training falls under three categories of monitoring. (1) The athlete uses self observation of their perceived heart effort, and breathing effort or how “out of breath” they feel to subjectively assess how relatively hard they are pushing themselves and how tired they are; (2) The athlete uses the same cues supplemented with objective values from a heart rate monitor; and (3) A trainer directly observes the exercise being performed and uses both their own personal experience with the individual, and their expert knowledge to assess from visual and auditory cues and possibly heart rate information, how hard the athlete is trying relative to their own ability and how much reserve energy is available for continued effort.

Prior Art in Aerobic Training Machine Monitors

[0018] Aerobic training machines include stationary bicycles, recumbent stationary bicycles, spinning bicycles, treadmills, elliptical training machines, rowing machines, cross country skiing machines, and stair climbing machines, among others. Electronics and programmability are important additional features on advanced aerobic training machines. A built-in heart rate monitor has become the standard on many cardio training machines. These built-in monitors typically require that the athlete grasp two conductive electrodes so that the heart signal can be picked up by the electrocardiogram (ECG) circuitry. These internal ECG devices are manufactured for example by the company Polar USA (www.polarusa.com). Polar makes a system that can be built into an exercise machine and communicate wirelessly with a Polar chest ECG sensor worn by the athlete. The heart rate results are automatically displayed on the display built into the cardio exercise machine.

[0019] Other than the heart rate, the electronics of cardio machines typically does not have the capability to measure other physical or physiological information from the athlete. Because of the lack of such information, the display on the exercise machine can only include information regarding virtual distance traveled, time exercised or information reflecting the machine level of difficulty settings.
Prior Art in Strength Training Machine Monitors

[0020] Even the most expensive and elaborate strength training machines (STM) typically do not have feedback displays for physiological measurements from the exercising athlete as these STMs are usually weight or resistance based and have no inherent need for electronic instrumentation. The exception includes some of the strength machines which use hydraulic resistance mechanisms. These types of STMs have an electronic display for their resistance settings and sometimes the number of repetitions. But even in those cases, the STMs typically do not have built in heart rate monitors. This may be because the manufacturers expect that the athlete will be using cardio machines for their cardiopulmonary training.

[0021] This situation seems to hold even though circuit training has become popular. The circuit training concept is that switching quickly between strength machines with no pause will thereby elevate heart rate and give a cardio workout at the same time as the strength training workout.

Prior Art in Fitness Training Classes

[0022] Group fitness classes are very popular at larger health clubs. These classes include gentle stretching as in yoga but more frequently are some type of aerobic training ranging from kick-boxing to step aerobics, hip-hop dance, and spinning or bicycling among others. The class trainer frequently instructs the class members to take their pulse rate manually. Increasingly, many participants use a personal HRM to ease their pulse taking during the exercise class.

[0023] The goals of such classes are often perceived as determining how hard the trainees should be working during the workout. Success is often measured on the basis of achieving targeted exertion levels (target zones) defined by percentages of the maximum heart rate (Max HR). Max HR is the highest heart-rate value that can be reached with an all-out effort to the point of exhaustion.

[0024] But basing the workout on Max HR is problematic. This is because the best method for determining Max HR remains an object of debate. The rule of thumb used in most aerobic classes is to estimate Max HR with the formula “220 minus your age.” However after research into the reliability of this method, exercise physiologists have concluded that Max HR cannot reliably be deduced using this simple equation. This is due in large part to the fact that Max HR is dependent on genetics more than age. In fact, most people of similar age do not have the same Max HR. Without accurate measurement of Max HR the target zones dependent on this value will also be inaccurate. Therefore classes conducted based on use of HRM cannot really achieve their stated objectives.

[0025] In fact, more accurate methods for estimation of Max HR employ maximal and sub-maximal tests to evaluate the body’s reactions to real aerobic loads. The most precise of these alternatives uses complex maximal oxygen consumption or maximal oxygen uptake (VO2 max) equipment to pinpoint the body’s biochemical reactions at various stages of exertion. While a maximal oxygen uptake test does yield an accurate determination of the true Max HR, it requires an all-out effort, is very physically demanding, requires supervision, and is not advised for those who are not already in relatively excellent shape.

[0026] All of the above mentioned prior systems are therefore deficient in their ability to serve as a platform for automated training of an athlete based on their individual capabilities. Prior systems use means for making their assessment of exercise level based on strictly heart rate thresholds that are derived from patient populations, but do not provide a means to generate individualized true level of effort assessments based on information more than heart rate. In particular, no prior exercise systems use body sounds, vital signs, and motions information to better assess personal level of effort. No prior art is able to put confidence values on the assessments of performance they determine. Likewise no prior art has provision for real-time tracking of personalized athletic assessment variables. Therefore no prior art can accurately perform an energy balance calculation and accurately determine when enough calories have been expended to provide for weight loss. Moreover, none provides means for continuous updating of their underlying training or coaching algorithms. Likewise prior art does not provide means to train simultaneously and also individually all the members of an exercise class based on objective measures of their personal fitness and activity level. No prior art has the means to automatically recognize the fatigue level of the athlete based on the motion on a machine or in control of movement on an exercise machine, much less use this information for coaching. Moreover no prior art has means to permit competitions between remote classes to serve as a motivational tool to help all the athletes achieve their best possible performance and reward the classes and individuals for their own efforts with respect to their personal capacities.

Objects

[0027] In view of the above state of the art, the present invention seeks to realize the following objects and advantages.

[0028] It is a primary object of the present invention to provide a method and system for monitoring multiple sites of body sounds, vital signs, and motions automatically and continuously, and thereby calculate measures of physiological rates and their variability in heart beat, breathing, and other physiological rhythms.

[0029] It is another object of the present invention to provide a method and system with means for the cancellation of background noise that has overlapping time and frequency components with body sounds, vital signs, and motions.

[0030] It is another object of the present invention to provide a method and system with means for separation of body sounds, vital signs, and motions on the basis of the rhythmic nature of these body sounds, vital signs, and motions, such as heart beats and the inhale/exhale cycle in lung sounds, with means for time-shared and individualized noise cancellation in order to identify the signal transmission channels iteratively, in real-time to separate body sounds, vital signs, and motions and to remove undesirable noise artifacts and to perform channel identification and noise cancellation.

[0031] It is another object of the present invention to provide a method and system with means for real-time and individualized adaptive pattern extraction display of extracted heart rates, breath rates, and other body signals along with variability of these quantities so that the individual engaging in physical activity can monitor the impact of their activity on these quantities.
It is another object of the present invention to provide a method and system with means for real-time and individualized adaptive pattern extraction of personal response to exercise that rates its quality in terms of confidence criteria.

It is another object of the present invention to be able to estimate maximum cardiopulmonary capability including for example Max HR and Max Lung Volume without uncomfortably or even dangerously high levels of effort.

It is another object of the present invention to provide a method and system with means for generating personal indices for exercise effort, physical stress, fatigue, and fitness levels.

It is another object of the present invention to provide a method and system with means for optimized dynamic recommendations for exercise geared to an individual’s personal goals.

It is another object of the present invention to provide a method and system which more accurately rates the current and accumulated level of effort of an individual engaged in exercise or physical activity based upon their personal vital signs and actual physical work being performed.

It is another object of the present invention to provide a method and system which can permit a trainer to observe a group of members of an exercise class from a supervisory system and track how each individual in the class and how the class as a whole is responding to and tolerating the activity.

It is another object of the present invention to provide a method and system which can permit multiple classes to compare their levels of effort with other classes at the same time so that contests can be held to reward both individual members of an exercise class or permit competition between disparate classes in order to reward absolute performance but also level of effort and group effort all while making sure no participant reaches a dangerous level for their health.

It is another object of the present invention to provide a method and system with ability to monitor physical activity and recognize imminent physical cardiovascular problems warn to prevent exercise from reaching dangerous levels.

It is another object of the present invention to provide affirmation for successful restriction of key parameters to a normal region, warning alarms for deviation of key parameters from their safe regions, and make remedial recommendations for activity based on the automated parameter trajectories.

It is another object of the present invention to provide a method and system which can manually recognize or automatically recognize a piece of exercise equipment and from a stored database remind an individual about how to adjust the machine to fit the individual’s body size and exercise level requirements.

It is another object of the present invention to provide user interface software which captures automatically or allows the operator to enter actual exercise performed including repetitions, force or weight levels, and number of sets among others relevant factors.

It is also an object of the present invention to provide a means to store the results of the completed daily exercise program and transfer for analysis to conventional personal computers in order to support analysis of progress.

It is also an object of the invention to allow the exercise machines to communicate with the present invention to make known the particular machine type and model so that the system of the invention remembers that machine and can remind the athlete of the preferred position settings for that machine and so that the proper ergonomic relations are achieved for comfort and safety and to also remember or store the optimum workout repetitions and weights to recommend to the user so that the workout objectives are best met by the large number of repetitions with low weight for maximum weight loss, or low number of repetitions and maximum weight or resistance for greatest muscle size or bulk gain.

These and other objects and advantages of the present invention will become more apparent from the description and claims which follow, or may be learned by the practice of the invention.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

SUMMARY

This application claims the benefit of Provisional Patent Application No. 60/783,424 filed on Mar. 17, 2006.

In order to optimally perform continuous monitoring and training of exercise, a personal exercise monitor and trainer (PEMT) system is provided. A Body Sound/Signal Analyzer module (BSA) is incorporated in the present PEMT system and methods which provide objective measurement of the level of effort expended by the user and make possible estimation of the remaining energy reserves. The BSA is a computerized cardiopulmonary analysis module which can separate overlapping body sounds, vital signs, and motions so that they can be utilized for real-time diagnosis. However it has analysis algorithms can be applied to any physiological signals. These processed sensor signals are combined within the present system and methods for further analysis with signals from additional physiological sensors. Informational parameters are generated from these signals, which include, for example, useful characteristics of lung and heart sounds, heart rates, and variability, respiratory rate, inhale and exhale duration and strength, magnitude, frequency center, frequency band, body oxygenation and exhaled gases, etc. Based on these informational parameters among others, the following pattern recognition module or stage uses a new methodology of multi-variable analysis to accurately estimate, among other variables, the effort level and energy reserves remaining for the particular individual.

Accordingly, a system and methods for physical training are provided which minimizes the burden of memory of machine settings, level of effort determination, physical monitoring, and progress record keeping among others upon the user and thereby maximizes the efficiency of exercise. The system and methods include a way to automatically or manually acquire information about which strength training or cardio machine the user is currently using to exercise. Advance setup of the system captures the
configuration information necessary to determine optimal physical position settings for ergonomics and proper level settings to meet that particular user’s training goals. Once recommended settings are implemented by the user, the system can communicate or interact with electronics on the exercise machine to acquire progress information including for example number of repetitions or virtual distance traveled. Alternatively motion sensors, for example accelerometers, can be reversibly placed on the machine or are built directly into the present system to estimate these values based on movements of the machine itself or motion values of the user. The method based on the information regarding the user progress, target level of effort, actual level of effort and current physical condition provides expert coaching recommendations in order to meet goals of weight loss, strength gain or cardio conditioning among others. The method and system can transmit the results of the workout to a remote system for data storage and record keeping. The system can likewise be implemented to perform all its operations on the remote computing device and use local display modules either attached to the exercise machines or transmit to mobile display units kept by each user. The method can include means to verify the safety of each user and make warnings before exercise might reach dangerous levels. In the case that an health risk situation does inevitably arise, the present system and method could immediately recognize the emergency and could use the information to activate internal communication means to summon first responders to the exact location of the person having medical problems.

In other features, an exercise system for training classes of students is provided. The system includes means to capture and display to an trainer data captured from each student individually and summary information for the class as a whole. This permits the trainer to give personal feedback to individual students while still optimally challenging the majority of the group. This set of features along with means for communication allows the disclosed system to be used in competitions between either subgroups within the single location or between locations with compatible systems. This feature can be used to further motivate the exercising participants through competition and contests. In alternative embodiments, means are included which translate combinations of the measured physiological sensor values and calculated levels of effort to control graphics on local or common graphical display units. These controlled visual displays will serve to feedback to the user a better sense of their progress and provide information for better gauging training progress and becoming trained to recognize personal physiological status and estimate self-observable parameters.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiments of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. 1 shows an overview of the personal exercise monitor and trainer system and its main sub-modules and their connections to empirical devices of the system and method in accordance with an embodiment of the present invention.

FIGS. 2a and 2b show two alternative personal exercise monitor and trainer or PEMT systems built upon different arrangements of sub-modules for the BSM module as it can be used in systems based on the present invention. FIGS. 3a, 3b, and 3c show the activity level determination process from an individual, from a cardio training machine, and from a strength training machine respectively.

FIG. 4 shows an exemplary hardware overview for a gymnasium equipped with personal exercise monitor and trainer systems.

FIG. 5 shows the flowchart of the process for PEMT Machine Database Setup and PEMT Gymnasium Setup.

FIG. 6 shows the flowchart of the process for PEMT workout setup.

FIG. 7 shows the flowchart of the process for PEMT workout operations.

FIG. 8 shows the flowchart of the process for PEMT reporting operations.

FIG. 9 shows an exemplary use of display software to make graphical display of PEMT system outputs.

FIG. 10 shows the usage of multiple personal exercise monitor and trainer systems to constitute a networked or PEMT based class system.

FIG. 11 shows the flowchart of the process for PEMT class trainer system operations.

FIG. 12 shows the flowchart of the process for PEMT class contest operations.

FIG. 13 shows a general overview of the function sub-modules of the BSM module and signal processing method which is at the core of the present invention.

FIGS. 14a, 14b, and 14c show alternative arrangements of sub-modules for the BSM module which can be used in systems based on the present invention.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.

The following discussion assumes the reader is familiar with personal coaching processes, cardiopulmonary testing and training equipment, strength training machines, and non-invasive physiological body sensors as applied to assisting with exercise training procedures.

The present disclosure describes various embodiments of a system and method for personal exercise monitoring and training that comprise means for (1) initial setup—as provided by a special exercise machine database containing, machine models, machine settings, range of values for each setting, and athlete database with alternatives for various workout schedules; (2) vital sign data capture and analysis—as provided by special body sensor capture noise cancellation, signal separation, pattern recognition, and diagnosis algorithms; (3) activity level capture—as provided by a combination of active and dynamic sensors which can capture motions and positions of any exercise
machines; (4) expert coach module—as provided by feedback of coaching advice based on analysis of the vital signs and actual activity level among other information and thereby making of recommendations as to how much harder, faster, or longer the athlete should exercise in order to optimally meet preprogrammed training goals; (5) multimedia display—as provided for example by a graphical display and speaker to remind the athlete with the setting values necessary to adjust the exercise machine under current use for their personal ergonomics and to effect their prompting with the number of exercise repetitions and levels or distances to be used as the current goal; (6) data capture—to provide, for example by touch screen capabilities, for the multi-media display of workout information such that corrections can be entered by the user to the setup settings and to provides means for data entry of the actual exercise performed; (7) record data storage—as provided by automated or user assisted entry of the performance data into a personal fitness database being used to populate the current workout exercise fields to permit progress tracking; and (8) internal user recognition—as provided by an embedded device identification process which provides means for an exercise machine to identify the current user, and as provided by locally or remotely stored setup information prompting the user with machine settings and recommended machine usage in terms of repetitions and intensity levels. Various embodiments of personal exercise monitoring and training methods and systems include various implementations and combinations of the above described elements as will be described in more detail below.

Hardware Overview of the Preferred Embodiment

[0070] As shown in FIG. 1, the personal exercise monitor and trainer system 500 is akin to a human coach in that it assesses the level of effort being expended by the athlete as well as the actual activity being performed. However, the PEMT system 500 does not guess at the level of effort but actually calculates these values objectively within the BSA-C processing module 230. The objective measures of activity level as determined by the activity level module 150 are combined with the level-of-effort values which are results of calculations by the PEMT Vital Analysis Module B 320 on signals from the vital sign sensors 30. The PEMT system 500 also contains information comprising personal characteristics for the athlete. This data can be gained by using the personal characteristics input module 510 which can allow the athlete for example to enter their age, and weight, and includes values such as their body fat percentage, body mass index (BMI), and resting heart rate among other general indicators of overall health and fitness. [0071] In an exemplary embodiment of the personal exercise monitor and trainer system 500, as shown in FIG. 1, the expert coach module 550 stores these values in the personal fitness database 520 to support basis of workouts on individual capacities and strengths as well as activity levels and levels of effort. [0072] As shown in FIG. 2, the sound sensors 30 are placed on measurement sites on an athlete 10 to capture body sounds, such as tracheal, bronchial, heart, etc., and for noise references. Sound waves acquired by the sensors will then be processed using the body sound or signal processing modules. As shown in FIG. 2a, if the vital sign sensors are acoustic sensors 31, then when using the BSA-B 220 sub-module for analysis, the personal exercise monitor and trainer system (PEMT) can display simple extracted quantities such as the heart rate, breathing rate, and heart rate variability and breathing or lung rate variability which allow the athlete to self-assess their exercise effort using much more complete information than that given by a simple heart rate. While body sound sensors alone are sufficient to support the simplest PEMT calculations, the inclusion of other vital sign sensors such as ECG or pulse oximetry sensors, allows the BSA-C 230 module to calculate more complex assessments of athletic efforts. For example, when chest movement sensors 32 are included to measure movement in the ribcage and movement in the abdomen, it is possible for the BSA-C 230 module to extrapolate values for tidal volumes and, as shown in FIG. 2b, extract individualized patterns which can support the calculation and display of the level of effort, physical stress level, level of fatigue, and even estimate the remaining energy reserve of the athlete or the percent capacity for physical activity remaining.

[0073] As shown in FIG. 2b, these values can be displayed graphically by an alphanumeric display on a watch type device, or even be sent in a wireless fashion to a device with graphical display capability such as a PDA with wireless connectivity. The PDA or some other computing device may contain the computing software to perform the filtering and noise removal as well as the BSA-C module 230 calculations, or these signal processing functions can be divided between a number of distinct hardware modules either residing closer to the vital sign sensors 30 and therefore worn by the athlete 10.

[0074] Any number of combinations of displays or feedback means of calculation results could be utilized to optimize ease of use by the athlete. For example, rather than a wrist based display or audio feedback through a headset or earphones, the athlete may wear a set of prescription or non-prescription eye glasses with means to function as a heads up display. For example, the athlete may wear glasses such as those disclosed in U.S. Pat. No. 6,801,363, which have the ability to act as a glasses mounted display. In this way, the athlete never has to modify their movements or activity to avail the assessment of their performance. This type of head mounted display arrangement permits the maintenance of best form while at the same time permitting the determination by the user of the PEMT system of maximal or optimum effort.

[0075] For the PEMT system or methodology to enhance or replace the function of a human trainer or coach, the PEMT can measure vital signs from the athlete, but also receive data on what constitutes the actual physical activity being performed. As shown in FIG. 3a, if the athlete 10 is exercising by performing calisthenics or body weight exercises, then the most practical way for the PEMT to calculate this activity level is by analysis of signals from motion and/or position sensors 110, for example accelerometers and coordinate sensors, which give movement values or relative positions of sensed body parts to a coordinate system in three dimensions. As shown in FIG. 3b, if the athlete 10 is exercising using some form of cardio training equipment such as a bicycle, recumbent bike, or treadmill type device 410, the suitable sensors can capture the virtual distance the athlete 10 has in effect traveled 114, the velocity of motion or for example some value of revolutions per minute (RPM) 116 from the roller mechanism on the equipment and some value of resistance 112. On a treadmill-type machine the
resistance value is typically replaced by the incline angle which when adjusted serves to make the athlete feel like they are walking, jogging, or running up a hill of a particular pitch.

[0076] As shown in FIG. 3c, the athlete 10 may be exercising with the objective of achieving increased muscle strength. In this case, a different set of sensor types is necessary to record the set of exercise machine values which more properly assess the muscle building activity. For strength training machines 420, the sensor types will typically include a sensor which measures the number of repetitions of complete movement 122, the weight setting typically measured in pounds or number of counter weight plates 120, and seat settings for body position or incline 118. These latter adjustments may affect the leverage necessary to move the weights and they therefore affect the activity level.

[0077] Weight lifters typically count the number of sets they complete in addition to the number of reps performed. The activity level module 400 shown in FIG. 3c contains analysis capabilities which allow it to determine whether the pause between repetitions is sufficiently long to consider these repetitions as belonging to a new set.

[0078] Therefore as shown in FIGS. 3a, 3b and 3c, based on measurements taken directly from sensors on the exercise machine itself or from the sensing of movement of the athlete’s body in space, and after capture of the sensor data by the data acquisition (DAQ)/filtering/noise removal module 55 to extract clean sensor signals, the activity level module 400 calculates assessment of the overall levels of athletic activity, work, and power that are being performed.

[0079] Shown in FIG. 4 is a hardware overview of one possible embodiment of a fitness center or health club which is enabled for use of the PEMT systems 500. However it is still possible for an individual PEMT standalone device to accomplish most if not all of the functions shown by the hardware in FIG. 4 although with manual or assisted operations by the athlete. As shown in FIG. 4, the athlete 10 wears the vital sign sensors 30 either on wrist, attached to chest or abdomen or elsewhere in order to make effective sensor contact. These vital sign sensors 30 communicate through direct or wireless connection with the main PEMT system 185. The PEMT PDA system 185 can communicate wirelessly with exercise machines such as STM 420 or CTM equipment 410 in the gym for example using an ID capturing device such as RFID, IR reader, laser scanner, or some other wireless means. This communication link can establish which exercise machine the athlete 10 is currently using. Alternatively the athlete 10 can manually set the machine identifier into the PEMT 185 using the built in input functions such as a key pad or touch screen display. The exercise machine 420 may or may not have its own ability to calculate and communicate the activity level automatically to the PEMT device 185. As depicted in FIG. 4, a local network 660 can facilitate communication with a supervisory computer 610 for PEMT units that spread throughout the whole gym. Said supervisory computer 610 then can assume much of the analysis and communications responsibilities of the individual training machines and the PEMT units. In some cases, it would only be necessary for the athlete 10 to wear the PEMT sensors 30 and the central computer 610 could perform the computing tasks ordinarily performed by the PEMT computing module 185. The trainer 20 as shown in this figure is able to monitor the activity of numerous athletes 10 which is especially useful during an exercise class.

[0080] FIG. 5 is flowchart diagram that details the process to perform the setup of the personal computer database for use with the PEMT device 180 shown in FIG. 1 especially as used in a gymnasium which expedites the use of the devices such as shown in FIG. 4. That is, the training machine database 710 in FIG. 4 is populated for a particular gymnasium using the process shown in FIG. 5. On the personal computer of the gymnasium, such as the PEMT server 610 shown in FIG. 4, the user runs a database application or a dedicated software program that creates the database of all exercise machines at the gym. As shown, the user selects an exercise machine to be entered into the training machine database 710. Each machine is first assigned an unique #. It can be the preference of the gymnasium management as to whether machines of identical manufacturer and model number are assigned the same identification number. This is a consideration because even machines which are manufactured to be identical can age differently over time and thereby have different impacts on a workout. Once each machine is given a unique identifier for database purposes, a human readable physical ID Tag is created and affixed to the machine in a permanent but conspicuous fashion. This ID Tag may in addition to being visually readable, use radio frequency technologies, may have bar code properties, or some other means can be used to make said ID Tag machine readable, scanable or detectable at a distance. Once the machine is tagged, this setup process solicits choice of what class of exercise the machine supports. This is because machines of same class for example, cardio training or strength training machines tend to be similar in function and therefore its setup in the database can be expedited by first determining to which class a machine belongs.

[0081] As shown in FIG. 5, in this representative embodiment, for each machine the ergonomic settings are first named and entered with their range of values. The ergonomic settings are those settings which are primarily dependent on a person’s skeletal dimensions and to a lesser extent their flexibility. Therefore, these values do not typically change with any amount of training. They are also not directly involved in the training process. They are therefore handled differently by the training machine database. Once the exercise is underway the ergonomic settings remain unchanged. Following entry of the ergonomic variables, the other setting types are entered which do change with the workout.

[0082] Also as shown in FIG. 5, if the machine being entered is a member of the cardio training machine (CTM) class the ergonomic settings are first chosen which will typically include seat height on a stationary bicycle, or distance from the pedals on a recumbent bicycle. Typically these are settings which have integer values between one and ten. Then the other setting types are named and entered with their range of values. For example, elliptical trainer machines frequently have a resistance or level of difficulty setting between 0 and 100. The speed setting measures from rest to zero strides per minute on up to whatever speed a human athlete can move on the machine which typically would not go over 200 strides per minute. Once both the
ergonomic settings and exercise specific settings are captured, this settings data is saved and stored in the training machine database 710.

[0083] If the machine being entered is a strength training machine (STM) the ergonomic settings are again first entered in this embodiment. For STM machines there are frequently settings for seat height, and for handle length, handle height, leg length, or arm length. Tilt angle for arms or body are also frequent ergonomic settings for STMs. All these variables typically have integer values between one and ten. Once these values are entered the setting types covering the specific exercise are entered. These will include for example the weight, incline angle and repetitions. Repetitions is an open quantity which is not set by the user of the machine and so no value is necessary for upper end in range of values for entry in the database. Again, once all the pertinent database fields are entered with name and range of values for ergonomic and exercise settings, this STM machine data is stored into the training machine database 710 for future usage by PEMT devices and methods.

[0084] FIG. 6 is a flowchart diagram that details the process to perform the creation of a personal workout and schedule for the personal fitness database 520 for use with the PEMT device 180 shown in FIG. 1, especially as used in a gymnasium which expedites the use of the devices such as shown in FIG. 4. As shown in FIG. 6, to expedite the creation of a personal workout, the training machine database 710 is downloaded to the PEMT based device. For the purpose of this embodiment, the PEMT is a PDA device with wireless communication capability 185. To create a workout, the athlete 10 can work directly with a personal trainer 20 who is experienced in creating personalized workouts, or may work by themselves and follow workout samples given in popular exercise books such as “Body for Life” by Bill Phillips or well known magazines such as “Muscle & Fitness.”

[0085] As shown in FIG. 6, the athlete 10 selects the first machine to be used in the new workout and then uses some means to capture the unique ID number associated with that machine as created in the process of FIG. 5. This capture of the ID number can be done remotely and automatically by the athlete walking up to the exercise machine and using an optical scanner, or an RFID receiver built directly into the PEMT PDA 185 device. These are just two of the many means that can be employed by the PEMT device to automatically identify the machine that is nearest the device. Once the exercise machine is uniquely identified the PEMT device calls up in software the set database of values for that type of machine created in FIG. 5. Then the PEMT software solicits from the athlete the particular values to be entered into the database for the athlete during that workout. For example, as shown in FIG. 6, if the athlete has selected a particular cardio machine, the PEMT software knows how many ergonomic values are necessary to completely setup that machine for the user. In this embodiment, that information came via download from the training machine database 710. Using the information from the training machine database 710, the PEMT workout setup software prompts the athlete with the name of the setting and can present the athlete with a range of values in a list to expedite the choice making.

[0086] In order to expedite choice making for ergonomic settings, the athlete can test alternatives on the machine itself. This is why a preferred method for workout creation is to create it in the gym where the machines are available for scanning of their ID tags and testing of setting values. Therefore, the athlete might sit on the seat and adjust its position to test the value before data entry and verify that it is the most comfortable setting. The most comfortable will typically be the safest and best setting for expediting the exercise process. Once the ergonomic settings are entered, the athlete likewise enters start setting values based on prompts from the PEMT workout setup software. The software for example will request for a treadmill the incline level setting, the speed setting in miles per hour, and also the time for the workout or the virtual distance to be traveled. In this fashion, the athlete is assisted in entering the crucial and complete information necessary to optimally use all the equipment. This information is no longer necessary for the athlete to remember as long as they can use their PEMT PDA device 185.

[0087] In this same fashion, the athlete can also create a workout which employs strength training machines. While this class of machines will tend to have different names of settings, the process is similar that the athlete must follow to add use of a STM to the particular workout. Workouts can be of any length. Although this practice is not typically recommended by trainers, PEMT workouts can mix both cardio and strength machines.

[0088] Once the ergonomic data and settings data are entered for each machine in the new workout, the athlete can name the workout and assign a schedule to it. For example, workouts programs are sometimes upper body and lower body on alternate days. Or for example, Mondays might be shoulders and arms and Tuesday can be legs and abdominals. Any schedule can be assigned to any workout and the PEMT PDA will then, depending on the schedule, and using the calendar capability built into the PDA, prompt the athlete with the preferred workout suggestions based on pre-selected schedules. The named workout is then stored in the personal fitness database 520 for that athlete on the PEMT PDA device 185.

[0089] In alternative embodiments, the athlete would have an identifying wristband or card key that each exercise machine would have a detector which could detect its current user. Alternatively, the athlete could manually identify themselves to the PEMT device on the exercise machine or the PEMT device on the exercise machine can have some biometric sensor to identify the user athlete. In this way, by moving between stations the athlete could be identified and the exercise machine could communicate with a central PEMT server and database to lookup both machine information and that athletes preferred settings.

[0090] FIG. 7 shows an exemplary method of an athlete interacting with the PEMT device 185. The user of the invention 10 can follow the flowchart of the process in FIG. 7 to assist in expediting workout operations. The athlete selects and runs the perform workout software program on the PEMT device. In this representative embodiment, the user is first prompted with the option of performing a scheduled workout or picking from a list of previously stored and named workouts. For example, if it is Monday, the PEMT software will offer the workout scheduled for Mondays first on the list of choices. Also on the list maybe items with names for body parts such as “chest and legs”, “arms and back” or “cardio distance”, or “cardio speed”, or “cardio hills”. The athlete may choose from one of the list
of previously created and stored workouts or may decide to follow a “manual” or freeform workout for that day.

The left half of FIG. 7 shows the PEMT workout process in the case of the athlete choosing a previously stored workout. Once a particular workout is chosen, the PEMT device displays which machine, is to be used for the first exercise. At the same time, or after acceptance by the athlete, the PEMT device displays the ergonomic settings and exercise plan for that machine. In the event that a machine recommended is broken, an option is given for eliminating that particular exercise for the day. In the event, that the machine required for the next recommended exercise is not available because it is already occupied, an option is given for skipping over that particular exercise until later in the workout. The athlete then adjusts the exercise machine by following the predetermined ergo settings.

As shown in FIG. 7, the program then guides the user through the settings for strength exercises by giving the start weight and number of repetitions to follow. If a sequence of weight levels and repetitions is part of the workout then the display will show this accordingly. As a set is completed it can be checked off as done using the touch screen display.

Also as shown in FIG. 7, if the next exercise in the workout requires a cardio machine, the PEMT device displays the incline level for a treadmill for example, or the resistance level for an elliptical machine for example. In most cases in order to completely instruct for performance of a cardio exercise, a speed, distance or time value will be displayed.

In alternative embodiments, the motion sensors can be either on the athlete or on the exercise machine and communicate by wireless or some other means with the PEMT and then that device can know for example exactly how many repetitions of an exercise were performed. Motion sensors on the athlete can be used by PEMT to actually count repetitions performed because PEMT analysis algorithms will recognize characteristic motion patterns of a person when using each machine type. In yet another alternative embodiment, the exercise machines have PEMT compatible motion sensors which can automatically count reps, and also detect and communicate other machine settings such as weight level, or the virtual distance actually traveled on a CTM. The exercise machine can even contain its own PEMT or some other sensor and analysis device with motion analysis algorithms which can on board the exercise machine itself assess for example the athlete’s ability to handle that weight level by analyzing smoothness of motion of repetition performance for that machine. This on board PEMT device then communicates wirelessly with the portable PEMT device of the athlete so that it can use that information directly for the expert coach module analysis and in this embodiment fewer sensors need be worn by the athlete.

In the exemplary embodiment shown in FIG. 7, the PEMT can monitor the vital signs of the athlete and can in real time recommend changes in cardio machine settings to challenge the athlete’s physiological response in the most accurate fashion. Not just heart rate but lung function and overall effort levels can be used to safely challenge an athlete in their workout performance. As the vital signs are monitored to control level of effort the overall workout length and difficulty can be adjusted by the PEMT to challenge the athlete to use a predetermined amount of energy reserves such as needed for distance training.

Most importantly, the PEMT is constantly analyzing the data from the vital sign sensors and the extracted parameters for dangerous reactions during exercise. The PEMT has different levels of reaction to medical dangers which can range from decreasing the difficulty of the workout, to warning the athlete, to actually summoning medical aid in the event the vital signs indicate an emergency situation. When the expert coach module within PEMT determines the athlete is overly stressed, has reached a level of too much fatigue, or has detected a sufficiently large loss of form or technique in performance of the exercise, the PEMT can recommend through its multi-media display anything to help the athlete recover which can include among other recommendations a water break, rest, doctor consultation, adjustment to the exercise routine by scaling back, or can even make an emergency phone call.

In addition to checking for medical emergencies, the PEMT expert coach module makes real time adjustments to the workout intensity based on overall goals and the vital sensors analysis. This real-time adjustment feature can be toggled on or off by the athlete depending on their feelings for that workout. On some days the athlete might feel energetic and desirous of a greater challenge, while on other days the athlete might feel for example a cold coming on and is not desirous to push their limits. However, the PEMT algorithms are designed to detect strength or weakness in the performance and vital sign reaction to the workout and can make recommendations accordingly.

As an exercise is completed, the athlete again can check it off as done by using the touch screen display of the PEMT device. In the event that more or less reps or deviations are made from the suggested weight or difficulty levels the changes performed can be manually entered by the athlete. If the workout is not complete as shown in FIG. 7, the process is repeated again with the PEMT displaying the next exercise on the workout list. This process continues until the workout is complete when the workout results in terms of exercises, deviations and vital sign summary are recorded for that workout and stored in the personal fitness database for future analysis and tracking.

The process of operation when the PEMT is used in a free form mode or when a previously stored workout is used is followed as shown on the right side of FIG. 7. In this usage case the athlete selects an available exercise machine and either automatically by some in some fashion means such as optical, magnetic, or RFID among others captures the ID number of the machine. The PEMT can then display the ergonomic settings and a list of previously stored preferred exercises using that machine. It can automatically search these previous uses of that machine from within any stored workout. After machine adjustment, the user can either follow a suggested exercise for that machine or use coaching from the expert coach feature of the PEMT to push their workout in a preconfigured fashion. The expert module may be set for example to a strength training mode which will recommend low repetitions and high weight or weight loss mode with high reps and low weight. The PEMT all the while is checking the vital signs and motion sensors for quality of performance and stress level for example. In this fashion the PEMT can mimic the processes that an experienced human coach follows but with much better understanding and insight into the real-time physiological response to the exercise by the athlete.
As in the use of preconfigured workouts, the process continues in this fashion for each exercise. However, in this case the process continues until the athlete indicates to the PEMT device that the workout is over. Again the workout followed and performed is recorded based on automatically acquired information and that manually entered into the PEMT by the athlete along with a summary of vital signs during the workout.

FIG. 8 shows the flowchart of the process for PEMT reporting operations. For use of the PEMT in a standalone operation mode, the PEMT is connected directly to the users personal PC. Daily workout results can be uploaded from storage within the PEMT device by the PEMT software program which also analyzes workout routines, calculates statistics, generates charts, and produces trends of progress in terms of workout and physiological effects. As shown in FIG. 8, graphs can be generated for trends in the athlete’s performance on specific exercises, overall changes in fitness levels such as cardio endurance and arm strength among others. The amount of calories burned during workouts as a function of time can also be graphed. These are mere examples of the types of analysis that can be generated when the PEMT data is uploaded. In the embodiment of FIG. 8, in addition to simple graphing and summary of performance and trending over time, the PEMT expert coach module 550 of the PEMT server is shown to make more advanced recommendations to produce a report that summarizes the current workout results in relation to goals and objectives of the exercise, comparison with related groups, and recommendations from exercise experts. In addition, inputs from a personal trainer, if available, can be incorporated into the analysis and reports. The output of this function will be stored in the personal fitness database 520 for future utility.

For use of the PEMT in server-based operation mode, all the functions performed above by the personal PEMT can be performed on a PEMT server remotely with wired or wireless connections to the personal PEMT. In this mode, the personal PEMT will serve as a connection node between the PEMT server and the trainee and the exercise facility.

As shown in FIG. 9, the display functions of the PEMT system include graphical and multimedia functions that can be integrated with typical software packages such as Real Player or Microsoft Media Player. The medium of display can be the PEMT screen itself, a TV screen, a computer screen, or a projector among others. For example, in Real Player or Microsoft Media Player, the related parameters such as motion, position, speed, and other physical values, can be transformed simultaneously into visual effects and music tunes with various rhythms, tones, frequencies, and power bands, for combined multimedia surrounding and visualization. The displayed values by the graphics program can be determined and set by any designated parameter levels from PEMT, such as values of the vital signs, level of activity values, level of effort, or some combination of these parameters. With such versatile display functions, the athletes and PEMT system users will have a real-time feedback display of their workout with an informative and comforting visual and audio environment.

As shown in FIG. 9, in an exemplary embodiment, the PEMT performs a process to captures the vital signs with signal interfaces and adaptors 810 and performs filtering and noise removal 55 to extract authentic physiological signals from noise-corrupted measurements. Then a series of signal processing functions follows to facilitate visualization and multi-media presentation. First the processed vital signs, which are usually collected with different sampling rates and time stamps, are synchronized and re-sampled 830 if necessary to be represented in a uniform time frame. Then, synchronized signals, which usually have different value ranges and precision levels, under a proper magnitude scaling process 840 to become compatible in their precision and relative value ranges in their computer representations. The characteristic parameter extraction module 850 is used to derive characteristic parameters from the signals. Typically, simple parameters such as heart rate, breath rate can be extracted relatively easily from signals. More sophisticated parameters such as effort levels and oxygen consumption volumes must be derived with more involved algorithms. Dynamic visualization mapping module 860 is a real-time interface function between extracted parameters and display software. This process module associates parameter values to designated display media selections such as color, music rhythms, among others. This allows parameter values to be displayed as visual and audio effects. The signals can then be displayed via a display software process 870, such as Microsoft Media Player, to expedite visualization and audio representation on any display devices 880.

Frequently athletes participate as a member in group training classes. Many people favor being in a class setting for their exercise rather than doing it alone. This may be because it is less boring, because of the added social value, or because it is motivational and motivates the class participants to push themselves out of a sense of general cooperation and competition. FIG. 10 shows how members of a class can each have their own PEMT system communicate their activity level and level of effort or in some cases just an overall level of effort or activity level of the group or combination of these. Through communication means as shown in FIG. 10 the PEMT system 500 can reside on an Ethernet network or even communicate via the internet to the PEMT class trainer server (CTS) 610. This PEMT CTS computer 610 runs supervisory software which combines all the class information into a summary report display of the whole class activity and also makes comparison of each student relative to the class average. In this way, the class trainer 20 can assess using objective data how the class as a whole is performing relative to overall goals and also how the individual students are performing relative to the group mean or average. If too many class members are not achieving the requested activity level it would indicate to the trainer 20 that the overall class goals are set too high or are too difficult. By contrast, if every athlete 10 in the class is exceeding the stated goals then these targets might be considered too easy by the trainer 20 and said targets can be modified accordingly.

As also shown in FIG. 10, the summary of class results can be displayed via a screen projector 670 for all class members to see on a large projection screen 680 located in front of the exercise studio or small monitors located throughout the room. Graphical indicators can be generated in the reporting software and visually shown to allow the student to judge how they compare to the group either through some distinguishing icon on the general screen 680 or by comparing displayed values on their personal PEMT 180 with the class averages displayed on the common display 680.
A system for competition or contest between disparate classes can be created based upon PEMT systems by having multiple class systems as shown in FIG. 10 having their PEMT class trainer server communicating in some means with each other through a supervisory computer, for example over the Internet. By sending information from multiple classes running simultaneously contests can be held between disparate health clubs or various organizations locally, or nationally, or even internationally. Multiple and various ways can be designed for winning the competition. The competition can be strictly based on activity level, for example which group pedals a longer cumulative virtual distance in a period of time, or which group lifts more pounds in a period of time or number of repetitions. But it is also possible to set rewards based on which class or individuals within are trying harder or have a higher level of effort. This reward process allows contest winners to not just be the biggest or strongest athletes but those that try the hardest or perform closest to their personal maximum capabilities. In the case of these contests the projector can display tracking in real-time of how one class is performing relative to the other contest participants.

FIG. 11 elaborates functional and operational procedures of the PEMT class trainer system depicted in FIG. 10. The flow diagram illustrates an exemplary process of training a class of athletes by using PEMT devices In the embodiment shown in FIG. 11, each participating athlete uses a PEMT device or during class. The device can be either be embodied as (1) PEMT standalone units or (2) a PEMT monitor unit built into the studio exercise equipment such as stationary bicycles among other exercise machines.

As athletes enter the class, they attach their vital sign sensors and establish communications between their PEMT device and the PEMT class trainer server via wireless networks or wired directly into the local gymnasium network or remote site by a wide area network (WAN). Once communication is established, the PEMT sends setup information identifier information to Class Trainer Server including (1) athlete unique identifier; (2) athlete demographics such as age, sex, and location; (3) athlete fitness data including for example their fitness level, health concerns, fitness goals, and Max HR among others. These values can be obtained from a setup file contained in the PEMT device with assessments either made by the device during prior workouts or entered into the device after testing by the personal or group trainer.

Once all the athletes have established communications between their PEMT devices and the PEMT class trainer server, and their devices have sent their necessary personal information, the trainer can start the class with instructions for the first exercise. As the athletes perform the exercise, their PEMT devices send vital sign data continuously and automatically to the PEMT CTS. The PEMT CTS combines all athlete data and performs data analysis: (1) checking vital signs to ensure individual athlete safety; (2) monitoring the individual progress for each athlete by comparing his/her efforts against the previous classes that athlete has taken; (3) summarizing the class or group results in tables and graphs; and (4) displaying these group results on the trainer’s monitor.

The trainer studies the individual and group report summaries and can then use this objective information to optimize the training of the class. In current group exercise situations the trainer can only tell how a student is doing by observing subjectively their movements and judging with experience their stress levels. The PEMT system makes it possible for the trainer to gain more comprehensive and objective information on the effort and stress levels of each athlete as well as the class with necessary statistics such as mean, variance, trend, and deviations from designated goals and objectives.

The class trainer server (CTS) displays for the trainer instantaneous and trend information: (1) athlete identifiers including perhaps their physical location in the exercise studio; (2) heart and lung breathing rates and their variability; (3) level of effort with respect to their personal target zone defined for example by the ranges of heart rate and respiratory rate; (4) critical conditions such as for example an unhealthy variability in heart rate; (5) summary statistics of the class, such as the percentage of the athletes who are in the desired target zone. This information among others allows the trainer to adjust the level and pace of training adaptively during the class. PEMT information processing can combine machine information such as RPMs in a spinning class with activity information such as motion sensors described in FIG. 10 to generate real-time condition data, and control machine settings to fit training programs if the exercise machine is equipped with such control functions.

As shown in FIG. 11, once the trainer can review the real-time summary information presented by the CTS the trainer provides feedback instructions to individuals and the class as a whole. After verifying that no class members are having medical difficulty, the trainer can give encouragement or incentive to any lagging students and give appropriate praise to the students that are achieving or exceeding their personal goals. Likewise, the trainer can assess the efforts of the class as a whole and adjust the difficulty levels to challenge the class without overly doing so. Also as shown in FIG. 11, this class training process can be repeated for each new exercise that the trainer assigns.

FIG. 12 is a process flow diagram illustrating an exemplary method for classes of athletes which are enabled with PEMT devices to hold physical exercise competitions in a remote fashion. This diagram summarizes steps for performing the class competitions using the PEMT class trainer system as illustrated in FIG. 10. In the embodiment shown in FIG. 12, each participating location or class is assumed to have all of their students enabled with a PEMT device during class and moreover in this exemplary embodiment each class competing in the contest has a class trainer server in order to participate.

As shown in FIG. 12, multiple PEMT class trainer servers establish communications with a remote class contest server or alternatively establish communications with a contest management website. Once connected, the class trainer registers their class for competition by uploading information identifying the contest level or degree of difficulty of competition and events that their group wants to compete, the number of athletes in the group, and perhaps the age distribution of the class among other pertinent information. Other types of information the trainer could indicate include proficiency ratings for example A, B, C for skill events such as bike riding or treadmill running and equipment type among others.

The remote contest server then (1) performs a matching of compatible registrants; (2) publishes rules for
the contest such as defining the contest events, for example a thirty minute bike ride at 90 RPM or at some heart rate zone; and (3) initiates the contest for example by firing a virtual starting gun on the class displays.

[0117] While the contest is in progress, the class trainer servers 610 send continuously a summary of the progress data of all their group's participants to the central class contest server 620. The class contest server 620 collates the information from the disparate participating groups for contest monitoring and analysis.

[0118] The class contest server 620 combines results from each group in a particular contest and sends the current standing information to the PEMT class trainer servers 610 and also sends additional summary information regarding for example individual standout performances back to the participant locations for display to their group. In this fashion, the groups essentially can get real-time feedback about their group's standings and this information can be motivational to get the group as a whole to try harder or work together. Each local participating club has a group display which presents the current standings for motivation of class members.

[0119] In an alternative embodiment, the class contest server 620 can update team standings and positions in a race and communicate the results to the participants by publishing on a contest website the real-time summary of standings.

[0120] Once the contest is over, be it a timed event or for example some virtual distance type event among other types, the class contest server 620: (1) analyzes final results; (2) judges the contest winners for both individual and group categories; (3) makes awards; and (4) publishes a summary of the contest results.

Body Sound, Body Sign and Motion Measurements

[0121] This invention introduces a monitoring system that is equipped with body sound, body sign, and motion sensors attached to multiple sites of a person's body to acquire body sounds and signals simultaneously and continuously. The system is capable of performing signal separation, noise cancellation, and computer-assisted signal pattern analysis. Based on the sensor data, the system provides a non-invasive means to accurately and promptly determine heart rate, lung or breathing rate, heart rate variability and lung rate variability among other physiological indicators.

[0122] FIG. 13 shows an overview of the BSA module 95 as previously disclosed in U.S. patent application Ser. No. 11/367,807. This module receives input from several body sound, vital sign, and motion sensors 30, performs associated data acquisition for measuring body sounds, vital signs, and motions continuously and provides means for output of results, including for example a digital display. It can provide extensive signal analysis in particular of heart and lung sounds but also of other vital signs and thereby provide the core functions for an improved exercise training device.

[0123] Shown in FIGS. 14a and 14b are scaled versions of the BSA module 95, which can be made to perform useful subsets of the total processing tasks shown in FIG. 13 and as such need to include fewer analysis modules and have the ability to perform less powerful functions. However with fewer analysis sub-modules, the derivative systems can be made smaller and for less cost. BSA-A module 210 can perform the extraction and separation of heart and lung sound or of other signals. BSA-B module 220 can perform all the functions of BSA-A module 210 with the added ability to perform pattern recognition. For completeness, as shown in FIG. 2c, BSA-C module 230 adds a sub-module to BSA-B module 220 in order to perform higher level abstractions in real-time on the extracted individualized patterns. Trending, diagnosis and the generation of conclusions based on changes in movements of the extracted patterns are performed by the real-time individualized optimal diagnosis sub-module 90.

[0124] The present invention combines output from body sounds, vital signs, and motion sensors with other non-invasive sensors for transcutaneous monitoring of respiratory gases and respiratory movement. For example, the transcutaneous oxygen sensor measures the PO2 through the skin and reflects skin tissue oxygen tension beneath it. Tissue oxygen tension is the primary goal of the peripheral circulation and hence it is the variable to track. This variable will follow the trend of arterial or PaO2 values during adequate blood flow states and follows changes in cardiac output during circulatory shock. Therefore PtcO2 can be included in the invention along with body sounds for determining the adequacy of ventilation.

[0125] Likewise, transcutaneous PCO2 is a noninvasive measure of tissue ventilation. This body sign can be useful for monitoring cardiopulmonary decompensation and for additional real-time assessment of the adequacy of tissue ventilation.

[0126] For real-time evaluation of respiratory efficiency during exercise, the non-invasive measurement of respiratory movement can be employed. For example, it has been shown that breath frequency undergoes changes when measured with an apparatus. The disadvantages of direct ventilation monitoring devices include (1) decreases in respiratory rate, (2) increases in tidal volume, (3) subject awareness that breathing is being monitored, (4) limited subject mobility, (5) difficult to implement in children, and (6) inability to implement for long term studies. These issues can all be detrimental if they occur during ordinary or everyday exercise situations.

[0127] In light of these problems with direct measurement of respiration, some scientific investigators have shown that respiration volume can be measured indirectly and non-invasively by recording motions of the chest. Respiratory motion reflects change in thoracic gas volume which under most circumstances is equivalent to spirometry measurements of tidal volume. Studies of the volume-pressure relationship of the ribcage and abdomen have shown that compartmental volume change or the volume exchange at the mouth is approximately equal to the sum of the volume change of the ribcage and abdominal compartments. While the contribution of these motions changes with posture, these values among others are alternatively used in the present invention as indicators of respiratory efficiency of an individual.

Multi-Sensor Body Sounds, Vital Signs, and Motions Monitoring System

[0128] The system of the invention includes a data acquisition module which consists of several sensors for measuring body sounds, vital signs, and motions continuously and a data input unit that is connected to a computing device. For convenience of operation and transport, all the hardware systems may be embedded in one overall system unit.

[0129] For sound measurements, the acoustic sensors can be of any types that are sufficiently sensitive to acquire body
sounds. These may include, but are not limited to, electronic stethoscopes, microphones, accelerometers, or special-purpose body sound sensors. The sensors will be attached to the designated auscultation sites and noise reference locations. In order to obtain noise measurements that represent the lumped impact of distributed and multi-source noises from the heart, lung, and other sound sensors, the noise reference sensors will be placed in the vicinity of the sound sensors. Some of the types of acoustic sensors require amplifiers to enhance sensitivity and signal/noise ratios. In these cases, amplifiers will be either connected to the sensors or embedded with the sensors in compact packaging. The outputs of the sensors will be connected to the data acquisition unit through signal wire interfacing, analog or digital, such as serial ports, USB ports, or wireless connections.

Other body signs and motions will be measured by respective sensors. For example, chest movements can be measured by pressure or motion sensors attached to a chest strap. Blood oxygen levels can be measured by a pulse oximeter. ECG can be measured with electromagnetic sensors.

The main software is embodied in a Body Sound/Signal Analyzer Processing System that contains all the modules for processing body sounds, vital signs, and motions. The signals are first conditioned and synchronized by the “Data Acquisition” module. To obtain authentic signals for body sounds, vital signs, and motions, signals are filtered to remove off-band and independent noises by the “Filtering” module and “ANC” module. A new advanced noise cancellation technique, embodied in the module “Time Shared Noise Cancellation”, has been developed to remove in-band and correlated noises. The “Signal Separation” module embodies the new cyclic system reconfiguration method to separate interfering signals. The “Pattern Recognition” module employs a stochastic pattern recognition algorithm that extracts key parameters for characterizing signal patterns with quantitative confidence levels. Then, the “Diagnosis” module identifies abnormal respiratory, cardiac, or other related conditions and diseases. Finally, the “Display and Storage” module provides a user interface for sound pattern feedback and display, information storage, and diagnostic outputs.

Noise Reduction

The noise reduction methodology of U.S. application Ser. No. 11/367,807 is uniquely designed to reduce the effect of signal/noise correlation. This method was derived on the basis of the unique nature of biological signals such as body sounds: (1) Breathing, heart, and upper airway sounds are not stationary, and usually have distinctive stages (inhalation, exhalation, and transitional pause in lung sounds, for example). (2) Sounds in signal-intensive stages, such as inhalation and exhalation stages in lung sounds, contain rich information about related body functions and can be processed for diagnosis. (3) During transitional pause, body sounds are very small and noises are dominant.

The noise canceling approach of this invention combines this unique method with the prior regular filtering techniques. The new method first uses a band-pass filter to eliminate the off-band noises (for example, sensors rubbing with skin or chest movement). After-filtering signals are then used in conducting channel identification during the pause interval, and noise cancellation during the signal-intensive stages. Upon establishing a reliable model of noise transmission channels, noise cancellation can be achieved even when signal and noise are highly correlated during inhalation and exhalation. Therefore, the method introduced in this invention complements the traditional filtering and ANC for applications in which time-varying statistical features render ANC ineffective, leading to significantly improved quality of noise cancellation.

The method of time-shared adaptive noise cancellation has been shown to reduce the impact of inherent noises on accuracy of sound pattern recognition [20,20,21]. The method of the present invention utilizes the unique features of lung sounds, heart sounds, snoring, and other body sounds. By combining cyclically reconfigured system identification for channel modeling, frequency-domain filtering, stochastic noise separation, the present method provides a far more robust and effective noise reduction than what was included in prior patents. Prior method patents proposed use of signal magnitudes and slopes to separate noise and signals. It is well known that such separations are not applicable to most noise cancellation cases. The noise cancellation method of the present invention includes the following new features. For concreteness, the detailed descriptions are given in examples with reference to lung sound, heart sound, and related respiratory signals. These are not to be viewed as the only domain of applications of this technology.

1. A virtual noise representation by placing noise reference sensors at strategically selected locations. These locations have two key requirements: (1) They do not receive too much targeted signals such as lung, heart, or snoring sounds. (2) They are relatively close to signal sensors such as those for lung, heart, or snoring sounds. Typical locations include shoulders, arms, but are not limited to these.

2. Location proximity between the targeted signals and reference sensors allows representation of noises from many sources to be approximated by a lumped noise near the reference sensor. The method replaces distributed noise sources (which are impossible to describe accurately and separately) with a lumped noise source.

3. Cycle separation of phases in signals such as lung, heart, and snoring sounds. In this example, while the overall sounds of heart, lung and snoring are not stationary processes, signals that are confined in separate stages are approximately stationary. For example, for lung sounds, the phases are inhalation, exhalation, and pause. For heart sounds, the phases are systolic, and pause. Mathematically, if all inhalation segments of a breathing sound are extracted and concatenated into a single waveform, then this waveform is approximately stationary. This formulation allows this invention to apply powerful modeling and signal processing methodologies that are applicable only to stationary processes.

3. Time-shared noise cancellation. It is observed that due to diminishing lung sounds during the pause interval, the correlation between the sound and noise in the pause interval is much smaller than that for inhalation and exhalation processes, leading to our time-shared adaptive noise cancellation algorithm. The measured lung sound during the pause stage is essentially the output of the noise channel in that interval. As a result, we can use input/output pair to identify the noise transmission channel in this interval. This will not require any assumption regarding independence of signals and noises. The key steps in the algorithm are:
During a pause stage, the measured noise reference (virtual input) and lung sound (output) are used to identify the noise channel.

During the inhale and exhale phases, the estimated noise channel model is used to extract the original lung sound.

4. Recursive algorithms for channel identification. Adaptive filtering and stochastic approximation algorithms are used to derive recursive algorithms to update noise channel models and to achieve noise cancellation, from cycle to cycle. This cycle-to-cycle recursion is computationally very efficient since models are updated by using only new measurements and no past data needs to be stored or remembered. Also, by gradually discarding old data via, for example, exponential discarding data windows, this method can in fact track time-varying channel characteristics, that can be used in continuous monitoring and diagnosis of breath sounds.

Enhanced method of noise cancellation by combining time-shared adaptive noise cancellation with filtering and stochastic separation. The time-shared noise cancellation is further enhanced by targeted filtering and stochastic separation.

Individually targeted frequency filtering. The novelty of this feature of the invention is to identify an individual patient’s baseline frequency ranges for targeted diagnosis conditions (such as “normal” and “crackling”) from initial data. These frequency ranges are then used to generate an individualized frequency filter that separates signals outside these frequency ranges since they are irrelevant to diagnosis targets.

Signal Separation

Signal separation involves two source signals s1 and s2. For example, in heart/lung sound separation problems, s1 is the heart sound and s2 is the lung sound. The measurements x1 and x2 are subject to cross interference from both source signals. A typical example in medical applications is separation of heart and lung sounds. In this case, the original source signals are heart and lung sounds. Their measurements, either by using stethoscopes or acoustic sensors, are subject to signal interference in which both heart and lung sounds are heard in each measured signal. The signal transmission channels are unknown. The goal is to generate authentic source signals s1 and s2 by using only the measurements x1 and x2. Since the channel transfer functions are unknown and may vary with time and/or operating conditions, they must be identified in real time. As a result, separation of heart from lung sounds becomes a problem of adaptive signal separation.

One key feature used in this invention for signal separation is the cyclic nature of these two signals: Each signal undergoes phases: signal emerging (inhale and exhale for lung sounds and heart beating for heart sound) and pausing (lung sound pausing in between inhale and exhale and heart sound pausing in between heart beats). This invention discloses how these vital signal features can be used effectively in separating the signals.

The main approach of cyclic system reconfiguration is explained as follows. The 2x2 system has two signal sources s1 and s2 and two observations x1 and x2. The observations are assumed to be convolution sums of the source signals, with unknown source-to-observation channels G12 (interference of sound 2 by sound 1) and G21 (interference of sound 1 by sound 2). The signal interference occurs when each observation contains signals from both sources. The signals from each source before interference from the other source are called p1 and p2, which are the authentic sounds that can be heard during auscultation without interference. The methodology of this invention is designed to recover p1 and p2. It is understood by those versed in the art that if all transmission channels are known, p1 and p2 can be directly recovered by mathematical inversion of the 2x2 system.

But the signal transmission channels G12 and G21 are unknown. As a result, obtaining p1 and p2 is a blind signal separation (BSS) problem. There exist many approaches to the BSS problem such as output de-correlation, higher order statistics, neural network based methods, minimum mutual information and maximum entropy, and geometric based methods. Although the underlying principles and approaches of those standard methods are different, most of these algorithms assume that the original signals are statistically independent and the separation processes are then dependent on this key property. The present invention introduces a new method to identify the unknown transmission channels by simplifying the complex BSS problem to a set of regular identification problems without any constraints on the independence of the source signals.

The new method of U.S. patent application Ser. No. 11/367,807 requires that the source signals should have some rhythms, namely the signals undergo intervals of existence and almost non-existence sequentially and yet are non-synchronized. Many biomedical signals bear these features, including for example heart beats, lung sound, and snoring. The approach of U.S. patent application Ser. No. 11/367,807 uses these features to reconfigure iteratively the transmission channels so that the blind identification problem can be reduced into a number of regular identification problems.

The following intervals are consequently recognized by the invention.

(1) Interval Class I: p1 is nearly zero and p2 is large.

In this case, x1=G21*p2 and x2=p2. As a result, sensor measurements x1 and x2 during Interval Class I can be used to identify the transmission channel G21.

(2) Interval Class II: p2 is nearly zero and p1 is large.

In this case, x2=G12*p1 and x1=p1. As a result, sensor measurements x1 and x2 during Interval Class II can be used to identify the transmission channel G12.

Once the transmission channels have been identified, this invention can get the desired separated signals p1 and p2 by inverting the transmission system.

Body Sounds, Vital Signs, and Motions Pattern Recognition

It is well understood in pulmonary medicine that there are no universal sound patterns or parameter thresholds that definitively indicate a disease or medical condition much less exertion level. Individualized pattern recognition that combines information from body sounds, vital signs, and motions needs to be established that is capable of capturing pattern shifting in each individual athlete. To advance the frontier in computer-aided body sound analysis to real-life applications, new methods are needed to develop individualized pattern recognition techniques.
The pattern recognition methodology of the present invention discloses a new technique of individualized pattern recognition and diagnosis [20,26]. The key properties of pattern recognition accuracy, confidence levels, noise impact, and noise reduction are rigorously established. The invention starts with a set of characterizing variables that can be extracted from body sounds, vital signs, and motions. For an example of lung sounds, these variables may include, but are not limited to, inhale length and strength, exhale length and strength, breath cycle length, breath in the time domain; and center frequency, power, frequency bandwidth, for inhale and exhale individually, in the frequency domain. Changes in these variables provide information to the invention algorithm for determination of lung sound pattern variations. The goals of sound pattern recognition and diagnosis in this invention include: (1) to dynamically capture changes in these key parameters; (2) to relate these changes to potential causes. The invention includes the following improvements over prior pattern recognition methods:

1. A general methodology to extract multiple parameters from body sounds, vital signs, and motions that can be used to characterize different patterns, depending on targeted applications. These parameters include, as an example, heart rates, and variability, respiratory rate, inhale and exhale duration and strength, magnitude, frequency center, frequency band, etc. Although the above variables have been used in their individual applications as useful characteristics of lung and heart sounds, a general methodology of multi-variable analysis is new. The new methodology is general and applicable if other parameters are used.

2. Individualized parameter distributions that are derived from data using stochastic analysis methods. It is well known that patient sound patterns vary dramatically and population patterns are not a good approach for diagnosis. This invention makes it possible to define individual baselines for diagnosis.

3. A dynamic pattern matching method that captures pattern shifting in each person. The main issue for sound pattern classification is to dynamically capture the changes of the individualized key parameters. To detect pattern shifting, this invention treats these calculated parameters, over each cycle of body sounds, vital signs, and motions, as stochastic processes. A method of windowed averaging with gradual data discarding is used to track pattern changes in a patient.

Individualized Diagnosis

A method of optimally selecting diagnosis regions to maximize accuracy of diagnosis is used. The method is based on a stochastic optimization procedure that uses a multi-objective performance index to minimize combined errors of “misdiagnosis” and “false alarm.” The invention method generates diagnosis regions accurately, individually, and objectively. This is in contrast to prior methods that use subjectively selected thresholds, which depend on “population average values,” or trial-and-error decision processes.

The diagnosis module utilizes a recursive decision process that is computationally efficient for continuously monitoring lung sounds. This includes a recursive method which updates diagnosis regions when new data have been acquired. Consequently, the method of the invention does not need to compute the regions repeatedly when observation of body sounds, vital signs, and motions produces new parameters continuously over a long period of time.

Physiological Indices

The diagnosis module of the present invention will generate physiological indices for physical effort, stress, fatigue, fitness levels. The module takes as inputs the main parameters generated from body sounds, vital signs, and motions by the pattern recognition module, as well as activity levels from exercise machines.

Activity level information from exercise machines and facilities defines personal characteristics, and the type, the load and duration of an exercise program. For example, for a treadmill, a person’s weight, platform incline angle, speed, and duration are the parameters that define the activity level. Similarly, on a stationary bicycle or rowing machine, the resistance and duration become the activity level measurements.

Physical effort is a relative measure of a person’s physical activity. This can be measured by many possible variables, depending on exercise goals. One typical example of physical effort indicators is a combined measure of heart rate, respiratory rate, and respiratory strength, and their variations. When a person performs exercise, his/her heart rate, respiratory rate, and respiratory strength increase. Relative increase of these parameters from the person’s normal values at rest before exercise and the rate of this increase over the course of the exercise show the person’s physical effort in exercise. On the other hand, for people with a specific goal of exercise, some other parameters may be used. For instance, for cardiac exercise, one may use first or second heart sounds as well heart rate to define physical effort levels. An analogy may also be drawn for weight-loss exercise in which integrated respiratory volumes over the period of exercise will be more directly related to physical effort level in calorie burning.

Fatigue levels are indicated by a combination of many factors. When a person is exhausted during an exercise, his/her heart rate, respiratory rate, respiratory volumes change, and also his/her pace of exercise will deviate. Typically, a slowing-down in the pace of bicycle peddling and/or certain body motion and postures form a common scenario of fatigue.

Physical stress is an undesirable condition during exercise. Short of breath, over-rated heart beating, panting in respiratory sounds, acute asthma, are typical stress indicators. There are more scientific and subtle signs of stress, such as heart beat variations, that provide further useful information on physical stress.

A person’s fitness level can be derived from a relationship among physical effort, activity level, and fatigue. An out-of-shape person must make a huge effort for a relatively low level of exercise activity. This is also reflected by relatively fast increase in their fatigue. In contrast, a well-trained athlete can endure high levels of activity with low effort and low fatigue.

This invention introduces a method and system that will use data from body sound parameters, body signs, and activity levels to generate measurable indices for physical effort, stress, fatigue, fitness levels. These indices can be generically expressed as nonlinear functions:

\[ f(hr, hrv, r, rs, rv, al, ep, \ldots ) \]
where hr=heart rate, hrv=heart rate variation, rr=respiratory rate, rs=respiratory strength, rv=respiratory volume, aL=activity level, eP=exercise pace, etc.

The actual function form for one specific application can be derived by population studies, statistical analysis, and data fitting. On the other hand, after establishing the function form from a representative population and targeted goals, the function can be further adapted to an individual by fine tuning its function coefficients using the individual’s exercise profiles and historical data on his/her physical effort, among other parameters.

Personal Identification and Workout Programs

A personal identification module of the present invention allows direct and fast communication between the person and the exercise facility. The module has the following main functions:

1. The exercise machine will recognize the person by an input device, such as a card scanner, RFID tag, IR reader, wireless reader, etc.
2. The workout history and designated current workout goal will enter the machine. The machine will adjust its speed, load, and duration accordingly.
3. The current workout results will be entered to the personal card or electronic memory storage device as part of the training record that can be carried with the person.

Personal Trainer Module

The personal trainer module provides advice for exercise levels and targets in real time, personalized to fit the individual needs. Currently, the most common advice in an exercise machine is the recommended range of heart rates, adjusted to the person’s age. The personal trainer module is a comprehensive functional software that performs the following functions:

1. In its display screen, an exercise level can be identified as a color-coded region in the parameter space. For example, when heart rate and respiratory rate are used jointly as physical effort levels, a region can be an area on the space with heart rate as the x-axis and respiratory rate as the y-axis. Consequently, a target exercise level will become a target region on the screen.
2. To reach the target region gradually the module displays the timed sequence of the intermediate desirable regions that move toward the target region as guidance for the trainee.
3. During an exercise, the module shows the physical effort trajectory vs. suggested trajectories of desired regions and provides suggestions in modifications in machine load (weight, incline angles, resistance forces, etc.), intensity (speed, pace, etc.), and duration.
4. During and after exercises, the module derives statistical data for the person to understand the current performance levels, comparative charts of training progress, and improvement of fitness levels, etc.
5. In relation to the goals designated by the person or a professional, the module adjusts target regions accordingly.

Personal Trainer Group Module

The main function of this module is to integrate data from many individuals in a group, such as a class, a club, an association, an age group, a population class, among others to perform statistics and to produce comparative information to guide and improve exercise programs.

The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the general design of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the intent and scope of the invention.

REFERENCE KEYS IN FIGURES

10 Athlete
20 Trainer
30 Vital Sign Sensor
31 Acoustic Transducer
32 Chest Movement Sensor
40 Filtering of Off-Band Noise
50 Adaptive Noise Cancellation for Independent Noise Removal
55 DAQ/Filtering/Noise Removal Module
60 Time-Shared Adaptive Noise Cancellation
70 Cyclic System Reconfiguration Method for Signal Separation
75 Combined Cyclic System Reconfiguration Method for Signal Separation and Noise Cancellation
80 Adaptive Individualized Pattern Recognition
90 Real-Time Individualized Optimal Diagnosis
95 Body Sound Analyzer System
100 Digital Display
112 Resistance Sensor
114 Virtual Distance Sensor
115 Revolutions Sensor
118 Incline Sensor
120 Weight/Level Sensor
122 Repetitions Sensor
150 Activity Level Module
180 PEMT Portable Digital Assistant System
185 PEMT Portable Digital Assistant w/wireless System
190 Computer System
200 Conventional Stethoscope System
210 Body Sound/Signal Analyzer Module A
220 Body Sound/Signal Analyzer Module B
230 Body Sound/Signal Analyzer Module C
310 PEMT Vitals Analysis Module A
320 PEMT Vitals Analysis Module B
400 Activity Level Mapping
410 Cardio Training Machine
420 Strength Training Machine
500 Personal Exercise Monitor and Trainer System
505 Personal Exercise Monitor and Trainer System w/wireless
510 Personal Characteristics Input Module
520 Personal Fitness Database
550 Expert Coach Module
600 Personal Exercise Monitor and Trainer Class System
610 Personal Exercise Monitor and Trainer Class Trainer Server
620 Personal Exercise Monitor and Trainer Class Contest Server
660 Network
670 Digital Projector
680 Projection Screen
REFERENCES


We make the following claims:
1. A method for automating exercise monitoring and training, comprising:
   a. capturing sensor signals of body sounds and vital signs and noises from a plurality of target locations, and removing off-band and statistically independent noises;
   b. performing adaptive individualized noise cancellation which further reduces noises;
c. performing a signal separation process which extracts authentic signals by reducing or eliminating signal interferences; and
d. performing pattern recognition to derive characteristic parameters and patterns with their values, and their trends along with quality ratings of these quantities.

2. The method of claim 1 wherein the multiple pulmonary-related sound signals and their derived parameters and patterns such as respiratory rates, respiratory rate variations, lung sound frequency spectrum are combined with cardio-related sound signals and patterns such as heart sounds, heart rates, heart rate variability to jointly characterize a person's cardiopulmonary functions and activity levels.

3. The method of claim 1 wherein:
   a. the sensor signals of body sounds and noises from a plurality of target locations are captured such that the distributed background noises can be approximated as lumped noise sources, off-band noises are filtered by pre-filters, and statistically independent noises are separated from useful signals by adaptive noise cancellation methods; and then removed;
   b. the adaptive individualized noise cancellation is performed by reducing noises that may have overlapping frequency components with the target signals or is statistically correlated with the target signals, whereby in-band and statistically correlated noises are separated by time-shared adaptive noise cancellation methods;
   c. the signal separation process which identifies the signal transmission channels iteratively and individually, separates interfered signals cyclically, and extracts authentic signals in real-time, all by using the cyclic system reconfiguration and signal separation methods; whereby target signals from multiple body signal sources that characterize body reaction to exercise and that have similar stochastic and frequency features are physically separated both from each other and also from extraneous sources of noise that may be statistically correlated with or have overlapping frequency components with the target signals, and
   d. the pattern recognition process is performed wherein the authentic signals obtained by said processing of background noise removal and signal interference reduction are further processed to derive characteristic parameters and patterns with their values, their trends along with quality ratings of these quantities in terms of statistical confidence criteria, all these are performed iteratively, adaptively, and individually in real time.

4. The method of claim 3 wherein said body signal sensors are acoustic sensors and for example measure heart and lung and airway sounds.

5. The method of claim 2 wherein said body sound sensors for respiratory and cardio functions further comprise additional body sign and vital sign sensors such as chest movement sensors to measure volume changes in chest and abdomen, oximetry sensors for measuring blood oxygen concentrations, and EKG for heart functions. The expanded set of signals is jointly processed with functionalities as in the method of claim 1 for sound signals that include:
   a. removing off-band noises with pre-filtering and removing statistically independent noises by adaptive noise cancellation;
   b. removing in-band and statistically dependent noises by the time-shared adaptive noise cancellation methods;
   c. separating authentic signals from signal interference by the adaptive and individualized cyclic signal separation methods;
   d. performing adaptive and individualized parameter and pattern extraction to derive characteristic parameters and patterns with their values, their trend along with quality ratings of these quantities in terms of statistical confidence criteria, all these are performed iteratively, adaptively, and individually in real time.

6. The method of claim 5 wherein the signals from body sounds, body signs, and vital signs are processed to estimate cardiopulmonary capabilities, such as Max HR and Max Lung Volume, from said sensors of measurements of body sounds and body signs.

7. The method of claim 6 further comprising means for performing real-time adaptive and individualized diagnosis whereby the parameters and patterns obtained by said parameter and pattern extraction methods are further processed to derive exercise related analysis and diagnosis, and presented so that the individual engaging in physical activity can monitor the impact of their activity from these quantities.

8. The method of claim 7 wherein said real-time individualized pattern recognition and diagnosis generates indices including at least one of exercise effort, physical stress, energy fatigue, and fitness levels of endurance, speed, power, and strength.

9. The method of claim 8 further comprising capturing activity levels by means of direct transmission from an exercise machine, from motion sensors located on said athlete, from sensors on the exercise machine, or by a combination of these means.

10. The method of claim 9 wherein said diagnosis recognizes imminent physical cardiopulmonary problems performs at least one of: (1) activating warning alarms for deviation of key parameters from their safe regions; (2) providing feedback indication for successful restriction of said vital signs, said physical activity levels or said indices to a normal region; and (3) making remedial recommendations for changes in said activity level based on the automated pattern trajectories thereby preventing exercise from reaching dangerous levels.

11. The method of claim 10 further comprising means for generating advice using an expert coach decision-making process which employs the expert decision logic stored in a database of exercise training rules, expert guidelines, and athlete training experience, together with said individualized pattern recognition and diagnosis, to analyze said activity levels to rate the current and accumulated level of effort of an individual engaged in exercise or physical activity, make comparison with the exercise goals, and generate individualized and optimized recommendations for exercise in real time.

12. A method for generating multi-media exercise activity displays for playing a combined graphical and acoustical summary of said real-time individualized pattern recognition and diagnosis comprising:
   a. capturing the signals:
   b. performing noise removal and signal separation functions to extract authentic signals;
   c. synchronizing signals in time such that all signals have compatible time stamps and sampling rates;
d. scaling signals in amplitude such that all signals have compatible relative ranges, precision levels, and data representation word lengths;

e. extracting dynamically characteristic parameters to be used for display functions;

f. creating dynamic visualization mappings of the extracted parameters to displaying variables such as shape, color, music tune, frequency, etc;

g. generating graphics for display of the mappings by creating commands compatible with display software such as Media Player;

h. generating tones for audible commands compatible with play by multimedia software such as MIDI sound software;

whereby the generated multi-media display provides the athlete with the ability to visually and audibly observe the impact of exercise on said signals of body sounds, body signs, vital signs, motions and said individualized pattern diagnose outcomes.


14. A computer program product for automating personal exercise monitoring and coaching of training, comprising:

a. a module for capturing vital sign signals of an exercising athlete;

b. a module for signal interfacing with measurement sensors, off-band noise removal by using pre-filtering, statistical independent noise removal by adaptive noise cancellation;

c. a module for removing in-band noise by using the time-shared adaptive noise cancellation methods, separating interfered signals to generate authentic signals by using the cyclic signal separation methods;

d. a module for deriving in real-time actual physical activity levels by processing authenticated signals of body sounds, body signs, vital signs, and motions;

e. a module for performing parameter extraction and pattern recognition of characteristic features of exercise levels, dynamic pattern tracking for dynamic trend analysis of exercise activity, optimal analysis and diagnosis for rating current exercise activity in relation to personal goals and expert guidelines, and the impact of physical exertion on these extracted patterns;

f. a module for inputting personal characteristics information to facilitate retrieval and entry of personal workout information;

g. a personal fitness database to receive information on personal exercise activity level, machine information, exercise activity record, and store them for tracking of longitudinal progress;

h. a module for expert coaching of training that makes recommendations to improve training results based on exercise rules, expert training guidelines, athlete training experiences, the activity levels and the extracted patterns, determining warning alarms for deviation of key parameters from their safe and desirable regions, making remedial recommendations to improve training and preserve safety, and populating the personal fitness database with history of exercise performance; and

i. a display module for presenting to said athlete the impact of exercise on the fitness levels and improvements, and trajectories of extracted key parameters that reflect exercise intensity and its impact on personal fitness and for presenting recommendations from the expert coach module.

15. The computer program product of claim 14 wherein the module for personal characteristics input further comprises user interface software which allows the operator to enter actual exercise results including repetitions, force or weight levels, and number of sets among others.

16. The computer program product of claim 15 wherein the product further comprises an interface which permits communication and transfer of said results of the exercise workout including said processed activity level and vital sign data for advanced analysis to a central server and for communicating data with and storing the records on the central server.

17. The computer program product of claim 16 for automating personal exercise monitoring and coaching of training wherein the product resides on a portable computing device.

18. The computer program product of claim 17 wherein the portable computing device includes a scanning device capable of automatically detecting and recognizing an exercise machine by at least one automatic and wireless means such as Bluetooth, RFID, barcode, and magnetic strip.

19. The computer program product of claim 18 wherein the portable computing device includes a wireless transmitter which permits communication with the gymnasium computer server.

20. The computer program product of claim 14 wherein said expert coach module presents an exercise from a stored workout specifying the next exercise to be performed by the athlete.

21. The computer program product of claim 14 wherein said expert coach module monitors the vital signs in conjunction with performance of an exercise and verifies the quality of the performance of the exercise by using at least one criteria including motion smoothness of said athlete during the exercise and smoothness of the athletes in controlling breath volumes, rhythms and rates prior to providing new recommendations for the subsequent exercise.

22. A system for automating exercise monitoring and training for a gymnasium, comprising:

a. an athlete wearing sensors for measuring body sounds, body signs, vital signs, and motions;

b. a plurality of exercise machines with unique identification tags for use in training by the athlete;

c. a portable computing device for automating personal exercise monitoring and coaching of training that captures signals of said sensors from the athlete and that can also manually or automatically recognize a piece of exercise equipment based upon the unique identification tag;

d. a personal exercise monitor and trainer server that receives, retrieves, and communicates the results of the workout by the athlete;

e. a local area network for supporting communication between the portable computing device and the server; and

f. a training machine database.

23. The gymnasium exercise monitoring and training system of claim 22 wherein the training machine database can be used to store, retrieve, and communicate information on machine settings to fit the individual's body size and exercise level requirements to achieve proper ergonomic relations for comfort and safety, and to store, retrieve, and communicate the workout program and workout results for
the athlete. The training machine database will store, retrieve, and communicate the alternative workout repetitions and weights to recommend to the athlete so that the workout objectives are best met.

24. The gymnasium exercise monitoring and training system of claim 22 that includes wireless or wired means on the exercise machines to communicate among said portable exercise device, the personal exercise monitor, and trainer server, to form a networked gymnasium exercise monitoring and training system.

25. The gymnasium exercise monitoring and training system of claim 24 wherein said trainer server includes an expert coaching module which can provide automated training and coaching.

27. The gymnasium exercise monitoring and training system of claim 25 wherein a number of class training systems communicate with a central class contest server which can automatically and in real time monitor exercise competitions among the multitudes of gymnasium locations with the class training systems.

28. The exercise contest training systems of claim 27 wherein the central class contest server can permit multiple classes to compare their levels of effort with other classes at the same time so that contests can be held to reward both individual members of an exercise class or permit competition between disparate classes in order to reward absolute performance but also levels of effort and group effort and also ensures that no athlete reaches a dangerous level for their health.

29. The exercise contest training system of claim 28 wherein the central class contest server judges said contest and rewards athletes based on at least one of a number of performance and activity level and extracted vital sign combinations during the contest.