(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 July 2014 (31.07.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/116559 A1

(51) International Patent Classification:
A61B 5/0488 (2006.01) *G06F 17/18* (2006.01)
G01R 29/26 (2006.01)

(21) International Application Number:
PCT/US2014/012253

(22) International Filing Date:
21 January 2014 (21.01.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/747,882 23 January 2013 (23.01.2013) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: SIGNAL QUALITY MONITOR FOR ELECTROMYOGRAPHIC SENSORS

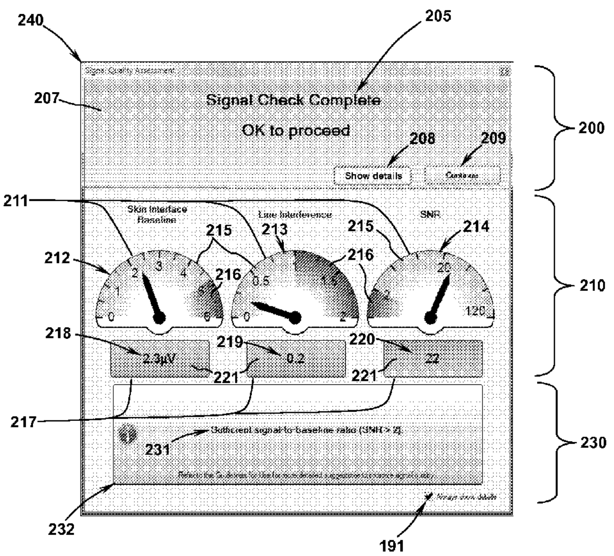


FIG. 10

(57) **Abstract**: A process for assessing the signal quality of electromyographic (EMG) sensor signal data outputs based of a set of time domain and frequency domain signal performance metrics, including the magnitude of the baseline noise, line interference power spectra, and signal to baseline noise ratio parameters of the signal, whose calculated values are compared with a set of pre-defined acceptable values to determine whether or not the signal is of acceptable signal quality, and provide a pass/fail output. A graphic and text display output includes the presentation of the calculated parameter values of the baseline noise magnitude, line interference magnitude, and signal to baseline noise magnitude, using a combination of digital and analog indicators, each marked with the respective value of their pre-defined performance metric. The visual display includes descriptive text blocks associated with each displayed parameter, with relevant instructions for addressing and correcting conditions of unacceptable signal quality.

WO 2014/116559 A1

SIGNAL QUALITY MONITOR FOR ELECTROMYOGRAPHIC SENSORS

TECHNICAL FIELD

This application relates to the field of sensing bio-potentials generated within a living body and more particularly, relates to assessment of signal quality of sensors used for detecting electrical activity from muscles using electromyographic (EMG) signals.

BACKGROUND

Depolarization potentials created during a muscle fiber contraction generate an electrical field gradient that propagates in a direction along the fibers throughout the volume conductor that includes the muscle, the surrounding tissue, and skin layers. Indwelling needle or fine wire electrodes placed within the muscle tissue or electrodes placed on the surface of the skin allow for the detection of this electrical field gradient providing the temporal summation of the propagating depolarization potentials of the active muscle fibers in the underlying vicinity of the electrode. Signal potentials emanating from the muscle tissue are conveyed via ionic transport through the tissue's electrolytes to the exposed conductive contact surfaces of the electrode. The resulting voltage is the electromyographic (EMG) signal.

Applications for using EMG signal measurement are diverse and can range from sports and ergonomic activities to the clinical evaluation of patients and neuromuscular research applications which investigate motor control. Analysis of the EMG signal can provide valuable information about muscle performance not obtainable by other means. The EMG signal amplitude may be representative of the force generated by the muscle, which, unlike externally applied force measuring devices, can be used to assess the individual force contributions from a group of muscles acting together on a joint. Multiple EMG sensors placed on the limbs can monitor muscle activity levels and coordination during, for example, gait studies or studies of neurological disorders such as Parkinson's disease. Changes in the frequency spectra of the EMG signal resulting from localized muscle fatigue can be used to more objectively assess appropriate activity levels and durations of tasks in the workplace. Specialized sensors developed to measure the firing patterns of the individual motor units of the EMG signal can be used to investigate motor control. Analysis of EMG signal temporal and spectral parameters may therefore be useful in all these investigations.

However, the voltage amplitude of EMG component of the signal detected by a sensor is inherently small, typically ranging from ten microvolts to several millivolts. In addition to the EMG signal component, the voltage at the sensor output includes the contribution from other noise sources generated by the inherent noise of the sensor's electronics, the electrolytic interface established between the metallic contacts of the sensor and intervening tissue, voltages induced by external power line sources, and voltages induced from the movement of the sensor contacts with respect to the intervening tissue. The summation of these intrinsic and extrinsic noise source components may be termed the baseline noise voltage.

The state of the art EMG sensor design minimizes the contribution of electronically generated circuit noise, however the predominate baseline noise sources relate to the sensor/skin tissue interface and are a function of contact design, skin preparation, and location of interference sources in the vicinity of the sensor. Variability in an individual's skin type and the amount of moisture and oils on the skins surface at different locations on the body affect the quality of the sensor/skin tissue interface and the resultant amount of baseline noise generated. This effect can be especially problematic when the electrolytic skin interface exhibits high impedance resulting from the lack of suitable moisture between the electrode contacts and the skin. This impedance can reach tens of meg-ohms for contacts with an area of 1mm squared placed on unprepared skin. Additionally, power lines and electrical equipment operating in the vicinity of the sensor may induce an undesirable level of 50/60 Hz frequency components and related harmonics into the sensor output if the sensor has been improperly applied to the skin. The contribution from all these baseline noise source components can be a large percentage of the overall signal output, especially for low level muscle contractions with low EMG signal amplitude, or sensor locations above muscles with large amounts of intervening adipose tissue.

The relationship between the level of EMG signal and the amount of baseline source noise is expressed as the signal to baseline noise ratio (SNR) where a higher SNR value indicates higher EMG signal quality. EMG signals with low SNR values can prove problematic in many applications that determine muscle performance using temporal and spectral analysis of the EMG signal. Minimizing the sensor/skin tissue interface noise and power line induced noise sources of the EMG signal baseline, while maximizing the available EMG signal amplitude by properly locating the sensor on the muscle ensures an acceptable SNR.

In many research based applications utilizing EMG, signal quality is assessed by visual observation of the EMG signal trace during data acquisition. Visual observation of EMG signal and the interpretation of signal quality by its nature are subjective, and dependent on the experience of a trained observer. The observer first estimates the amplitude of the baseline envelope and any periodic interference components of the sensor output during the quiescent state. The amplitude of the EMG signal during a contraction is then noted, and the signal quality is determined based on these observations. This procedure is repeated for each attached sensor. Determining signal quality in this way may be acceptable for preliminary investigations where there is both adequate time and personnel. However, for clinical research applications, this approach may prove cumbersome for protocols where multiple tests are performed with multiple sensors. Furthermore, there are situations where it may be difficult to visually distinguish the level of periodic interference components within the baseline noise envelope and the SNR of low level EMG signals. Most signal quality tests are performed when the sensor is initially applied at the outset of the data acquisition and may not be repeated during subsequent trials, increasing the risk of poor data quality.

Some clinically based EMG systems such as those specifically designed for applications to measure EKG with separate, individually applied skin electrode contacts have features which automatically determine baseline signal quality by measuring the impedance of each contact. A low impedance reading indicates that the contact is attached to the skin. High impedance indicates that there is poor contact or that the electrode has become detached and a warning condition is issued. These clinical devices measure signal quality as it relates specifically to monitoring the EKG signal, however, the EKG signal is not representative of the temporal and spectral characteristics of EMG signals obtained with differential sensors during voluntary muscle contractions. Voluntary contractions associated with EMG signals can vary in amplitude as function of contraction level from baseline noise to maximum voluntary contraction depending on the selected contraction profile. The EMG signal amplitude is at least an order of magnitude lower than the EKG signal. The level of sensor/skin tissue interface and power line induced baseline noise sources, which may not be a significant issue for monitoring EKG signals, could be problematic for monitoring low level voluntary EMG signals. Because of the greater frequency bandwidth (up to 500 Hz) of voluntarily elicited EMG signals, the effect of baseline noise with higher frequency components may be a more predominate factor in determining signal quality than in EKG applications. And while using impedance measurement to determine signal quality might seem a useful technique for voluntary EMG measurements, it can prove problematic, especially for differential pair sensors with a 1cm to 2 cm inter-electrode spacing. As a rule, the lower the electrode contact impedance with the skin, the lower the baseline noise value. With a differential inter-electrode spacing used by sensors designed for voluntary EMG measurements, a low electrode contact impedance reading could be interpreted as a properly applied sensor with low baseline noise. However, a low impedance reading could also mean that there is excessive moisture acting as an electrical short between the contacts which would attenuate the EMG signal, leading to a lower than expected SNR. Therefore for sensors used in voluntary EMG measurements, the determination of the actual baseline noise value, combined with assessment of SNR is superior to impedance measurement in determining inter-electrode shorting due to excessive moisture.

The signal quality assessment techniques utilized by clinical devices such as EKG monitors may have limited applicability for use in measurement of signal quality for voluntarily elicited EMG signals because EKG assessment techniques (and similar) do not provide a quantifiable indication of the output levels of baseline noise, power line interference, and SNR to the user. It is the unique combination of these parameters which provides a comprehensive assessment of signal quality in applications utilizing voluntarily elicited EMG signals. Some existing designs of EMG equipment address the issue of signal quality by utilizing electronic circuit hardware to measure the EMG signal saturation (clipping) and the level of power line interference contamination. The equipment may provide visual and audio output by lights and buzzers when a hardwired limit is exceeded, but does not measure the baseline noise value or compute the SNR value, and may lack the ability to perform spectral analysis to determine the level of harmonically related periodic components of the power line frequency. While a useful aid in finding catastrophic failure conditions such as sensor detachment, such equipment may lack the sophistication of providing a complete interpretation of signal quality.

All of the aforementioned configurations offer only a limited set of solutions for determining EMG signal quality required as a prerequisite for the successful execution of a given clinical or research EMG application utilizing the measurement and analysis of voluntary EMG signal. It would be useful to provide an automatic EMG sensor signal quality assessment process that would ensure the acquisition of data with proper signal quality necessary for the successful execution of a clinical or research EMG application.

SUMMARY OF THE INVENTION

According to the system described herein, evaluating at least one of a plurality of EMG sensor signal data outputs includes determining regions of baseline noise, line interference, and summated motor unit action potential components for each of the plurality of the signal data outputs, arithmetically combining corresponding time and frequency domain parameters of each region into parameters to provide a set of calculated electromyographic signal performance metrics that include a baseline noise value, a magnitude and power spectra of a summated motor unit action potential components, a line interference spectra value, an EMG signal to baseline noise ratio, and a maximum data value, visually displaying the calculated electromyographic signal performance metrics, comparing the calculated electromyographic signal performance metrics with a set of pre-defined electromyographic signal performance metrics values, providing an output indicating an acceptable signal quality result in response to all of the calculated performance metrics meeting the pre-defined electromyographic signal performance metrics, and providing an output indicating a non-acceptable signal quality result in response to at least one of the calculated performance metrics not meeting the pre-defined performance metrics. There may be one EMG sensor signal data output or there may be more than one EMG sensor signal data output. The set of pre-defined electromyographic signal performance metrics may be determined according to performance requirements of a selected EMG application, and may include an allowable number of segments from a baseline region containing motor unit action potentials, an allowable value for the EMG signal to baseline noise ratio, an allowable maximum value for a signal data output, values of coefficients of variables used in mathematical functions that arithmetically combine a plurality of individual parameter values into single respective parameter values, values of coefficients of variables used in a mathematical function that calculates an allowable baseline noise value based on the EMG signal to baseline noise ratio, and values of coefficients of variables used in a mathematical function that calculates an allowable value for spectral components of the line interference based on a calculated value of the EMG signal to baseline noise ratio and a calculated value of the summated motor unit action potential components power spectra. Determination of the summated motor unit action potential component may include an algorithm designed to identify data segments containing motor unit action potentials and calculate a summated motor unit action potential components region signal envelope and where the magnitude of the summated motor unit action potential components region signal envelope may include in the calculated performance metrics. Determination of the line interference component may include an algorithm designed to calculate a power spectral density function of the baseline noise and to identify magnitudes of 50 Hz, 60 Hz, and associated harmonic components of the EMG sensor signal data and where the magnitudes of the components of line interference may be included in the calculated performance metrics. Determining regions of baseline noise may include an algorithm designed to divide a signal envelope of the summated motor unit action potential component by a baseline noise region signal envelope and provide a result thereof as the signal to baseline noise ratio where a magnitude of the signal to baseline noise ratio may be included in the calculated performance metrics. Determination of the maximum data value may include an algorithm designed to calculate a maximum absolute value of the data and the maximum absolute value may be included in the calculated performance metrics. The calculated performance metrics may include a mean value of a magnitude of a baseline noise region signal envelope, a mean value of a line interference spectra magnitude, and a mean value of the signal to baseline noise ratio, where each of the mean values may be calculated from a plurality of individual parameter values. An allowable value for a baseline noise signal envelope may be calculated as a function of a pre-defined value of allowable baseline noise and the calculated signal to noise ratio. An allowable value for the spectral components of the line interference may be calculated as a function of a pre-defined value of allowable spectral components of the line interference and the calculated signal to noise ratio. A compliance state of a recorded signal quality result output may be provided as an accessible digital control output available for integration with other hardware and software processes. A visual graphic display presentation of results output may be expanded by user activated control to include presentation of calculated parameter values of the baseline noise, line interference, and signal to baseline noise ratio, using a combination of digital and analog indicators, each marked with a value of the pre-defined performance metric for respective output parameters thereof, where the visual graphic display presentation may include presentation of additional descriptive text blocks associated with each respective calculated parameter value output. The visual graphic display presentation of results output may be automatically expanded to include presentation of calculated parameter values of the baseline noise magnitude, line interference magnitude and signal to baseline noise magnitude using a combination of digital and analog indicators, each marked with the value of the pre-defined performance metric for respective output parameters thereof. The visual graphic display may include presentation of additional descriptive text blocks associated with each respective calculated parameter value output having text content based on context determined by a state of compliance with a set of pre-defined performance metrics values. The descriptive text blocks may provide instructions for addressing and correcting conditions of non-compliance of each calculated parameter value output with respect to the set of pre-defined performance metrics values.

According further to the system described herein, computer software, provided in a non-transitory computer-readable medium, evaluates at least one of a plurality of EMG sensor signal data outputs. The software includes executable code that determines regions of baseline noise, line interference, and summated motor unit action potential components for each of the plurality of the signal data outputs, executable code that arithmetically combines corresponding time and frequency domain parameters of each region into parameters to provide a set of calculated electromyographic signal performance metrics that include a baseline noise value, a magnitude and power spectra of a summated motor unit action potential components, a line interference spectra value, an EMG signal to baseline noise ratio, and a maximum data value, executable code that visually displays the calculated electromyographic signal performance metrics, executable code that compares the calculated electromyographic signal performance metrics with a set of pre-defined electromyographic signal performance metrics values, executable code that provides an output indicating an acceptable signal quality result in response to all of the calculated performance metrics meeting the pre-defined electromyographic signal performance metrics, and executable code that provides an output indicating a non-acceptable signal quality result in response to at least one of the calculated performance metrics not meeting the pre-defined performance metrics. The set of pre-defined electromyographic signal performance metrics may be determined according to performance requirements of a selected EMG application, and may include an allowable number of segments from a baseline region containing motor unit action potentials, an allowable value for the EMG signal to baseline noise ratio, an allowable maximum value for a signal data output, values of coefficients of variables used in mathematical functions that arithmetically combine a plurality of individual parameter values into single respective parameter values, values of coefficients of variables used in a mathematical function that calculates an allowable baseline noise value based on the EMG signal to baseline noise ratio, and values of coefficients of variables used in a mathematical function that calculates an allowable value for spectral components of the line interference based on a calculated value of the EMG signal to baseline noise ratio and a calculated value of the summated motor unit action potential components power spectra. A compliance state of a recorded signal quality result output may be provided as an accessible digital control output available for integration with other hardware and software processes. The system may also include executable code that provides a visual graphic display presentation of results output that are expanded by user activated control to include presentation of calculated parameter values of the baseline noise, line interference, and signal to baseline noise ratio, using a combination of digital and analog indicators, each marked with a value of the pre-defined performance metric for respective output parameters thereof, where the visual graphic display presentation includes presentation of additional descriptive text blocks associated with each respective calculated parameter value output.

The system described herein is a process for assessing the signal quality of EMG sensor signal data outputs based of a set of signal performance metrics including the magnitudes of the baseline noise, line interference power spectra, and signal to baseline noise ratio parameters of the signal, whose calculated values are compared with a set of pre-defined acceptable values to determine whether or not the signal is of acceptable signal quality and output a pass/fail result. A graphic and text display output is provided to visually indicate the results. The visual display includes the presentation of the calculated parameter values of the baseline noise magnitude, line interference magnitude, and signal to baseline noise magnitude, using a combination of digital and analog indicators, each marked with the respective value of their pre-defined performance metric. The visual display includes the presentation of descriptive text blocks associated with each displayed parameter, with relevant instructions for addressing and correcting conditions of unacceptable signal quality.

The system described herein relates to an improved mechanism for automatically determining whether or not the quality of the signal data acquired from EMG sensors is suitable for successful execution of a clinical or research EMG application and, if necessary, suggests a sequence of corrective actions that should be taken in order to ensure the acquisition of data with proper signal quality. The system described herein is applicable to all EMG sensor technologies including indwelling sensors such as needle and fine wire electrodes, as well as bipolar and multi-contact surface array sensors. The system described herein is unique in that it takes into consideration the compounding effect of the multiple intrinsic and extrinsic factors which influence the quality of the EMG signal.

The system described herein may be applied to one or more EMG sensor signal data outputs. The system described herein may provide real-time output of signal quality during data acquisition. The system described herein may be included as one of the steps in a sequence of steps defining a protocol used to acquire data. The system described herein may be included as one of the steps in a sequence of steps defining a protocol used to analyze the acquired data. The system described herein may determine regions of baseline noise and regions EMG signal activity within the acquired data. The EMG signal activity may be the result of voluntary muscle contraction. The system described herein may combine the respective calculated the time and frequency domain parameters of selected regions of baseline noise and EMG activity simultaneously acquired from each output of a group of multiple EMG sensor signal data outputs, to create a representative value for each parameter. The time domain parameters may include the magnitude of the baseline noise envelope, the magnitude of the EMG activity envelope, the maximum absolute value of the acquired data, and time stamps defining the locations of the selected regions of baseline noise and signal activity within the acquired data. The frequency domain parameters may include the magnitude of selected line interference frequency components of the power density spectrum of the selected regions of baseline noise, and the median or mean frequency of the power density spectrum of the selected regions of EMG signal activity within the acquired data. The system described herein may calculate the time and frequency domain parameters of selected regions of baseline noise and EMG activity within the acquired data. The system described herein may divide the magnitude of the envelope of the selected regions of EMG signal activity by the magnitude of the envelope of the selected regions of baseline noise and expresses the calculated result as the signal to noise ratio. The system described herein may allow the value of the magnitude of the envelope of the selected regions of baseline noise may be a function of the calculated the signal to noise ratio. The allowable value of the magnitude of selected line interference frequency components of the power density spectrum may be a function of both the calculated the signal to noise ratio and the median or mean frequency of the selected regions of EMG signal activity. The calculated time and frequency parameters of the baseline and EMG signal regions, together with the calculated signal to noise ratio, may form a set of calculated signal quality performance metrics. The system described herein may use a multi-parameter determination algorithm to compare a set of the calculated values of the signal quality performance metrics with a set of pre-defined EMG signal performance metrics values to provide an output indicating an acceptable signal quality result when all the calculated performance metrics meet or exceed the pre-defined performance metrics, and may provide an output indicating a non-acceptable signal quality result when any of the calculated performance metrics do not meet the pre-defined performance metrics. The output of the system described herein indicating the state of compliance with the set of pre-defined performance metrics may be a Boolean value that can be used for conditional control. The system described herein may provide a visual display output of the system described herein indicating the state of compliance with the set of pre-defined performance metrics. The system described herein may provide visual display presentation of additional descriptive text blocks associated with each respective calculated parameter value output, whose text content is based on the context determined by the state of compliance with the set of pre-defined performance metrics values. The system described herein may provide visual display presentation of descriptive text blocks provide instructions for addressing and correcting conditions of non-compliance of each calculated parameter value output with respect to the set of pre-defined performance metrics values. The visual display presentation of results output may be optionally expanded by user activated control, to include the presentation of the calculated parameter values of the baseline noise magnitude, line interference magnitude, and signal to baseline noise magnitude, using a combination of digital and analog indicators, each marked with the value of the pre-defined performance metric for their respective output parameter. The visual display presentation of results output may be automatically expanded during the output state of non-compliance with the set of pre-defined performance metrics, to include the presentation of the calculated parameter values of the baseline noise magnitude, line interference magnitude and signal to baseline noise magnitude using a combination of digital and analog indicators, each marked with the value of the pre-defined performance metric for their respective output parameter.

The system described herein replaces the subjective interpretation of signal quality based on visual observation or based on preset hardware based limits, with a more comprehensive series of software based algorithms which parameterize and integrate the multiple extrinsic and intrinsic factors which affect electromyographic signal quality. These parameters are compared with a knowledge base of pre-defined metrics established for a given application to determine a pass/fail result. The visual graphic outputs of data and instructive text display outputs provided by the assessment further simplify the task of correcting conditions indicating poor signal quality. The technique could be applied to all types of sensor technologies used to acquire the EMG signal, including those incorporating needle, fine wire, bar and pin electrodes, as well as multiple sensor arrays.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the invention will become more apparent upon perusal of the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a system block diagram illustrating an embodiment of the system described herein;

FIG. 2 is a block diagram of a baseline noise and EMG signal activity region selection algorithm according to an embodiment of the system described herein;

FIG. 3A is a plot of a selected baseline region according to an embodiment of the system described herein;

FIG. 3B is a plot of a selected baseline region with motor unit pulses according to an embodiment of the system described herein;

FIG. 4 is a block diagram illustrating baseline noise MU removal according to an embodiment of the system described herein;

FIG. 5A is a time domain plot of a baseline noise and EMG signal activity regions of an EMG sensor signal data output according to an embodiment of the system described herein;

FIG. 5B shows a plot of a calculated Baseline Noise Power Density Spectrum plot according to an embodiment of the system described herein;

FIG. 5C shows an EMG Power Density Spectrum plot according to an embodiment of the system described herein;

FIG. 6A is an expanded view of a selected baseline region of a signal according to an embodiment of the system described herein;

FIG. 6B is a Power Density Spectrum plot of a signal baseline noise signal according to an embodiment of the system described herein;

FIG. 7A is an expanded view of a selected baseline noise region of a signal contaminated with power line interference according to an embodiment of the system described herein;

FIG. 7B is a Power Density Spectrum plot of a baseline signal contaminated with power line interference according to an embodiment of the system described herein;

FIG. 8 is an expanded view of EMG signal activity region where portions of a signal are clipped at maximum data values according to an embodiment of the system described herein;

FIG. 9 is a block diagram illustrating performance metrics comparison matrix selection according to an embodiment of the system described herein;

FIG. 10 is an example screen shot of a video display of a signal quality assessment indicating a Pass result according to an embodiment of the system described herein;

FIG. 11 is an example screen shot of a video display of a signal quality assessment indicating a Fail result according to an embodiment of the system described herein;

FIG. 12 is a block diagram of another embodiment for processing multiple signal data channels according to an embodiment of the system described herein;

FIG. 13 is a block diagram of baseline noise and EMG signal activity region selection algorithm according to an embodiment of the system described herein;

FIG. 14 is a block diagram of an algorithm used to combine multiple calculated data outputs according to an embodiment of the system described herein;

FIG. 15 is an example screen shot of a video display of a signal quality assessment for multiple signal data channels indicating a Pass result according to an embodiment of the system described herein;

FIG. 16 is an example screen shot of a video display of a signal quality assessment for multiple signal data channels indicating a Fail result according to an embodiment of the system described herein;

DESCRIPTION OF VARIOUS EMBODIMENTS

Referring to **FIG. 1**, a system **11** assesses signal quality of EMG sensor signal data outputs using a set of signal quality compliance algorithms **12**, generated visual graphics and text displays **13**, and a digital pass/fail result output **153**. The sensor data may be from a single differential EMG sensor or from a double differential EMG sensor placed on the skin of a subject. The system **11** may be implemented using hardware (e.g., off-the shelf computer processing hardware), software (e.g., a computer program written in an appropriate language to provide the functionality described herein), or some combination thereof. In an embodiment herein, the system **11** may be implemented using a computing device such as an off-the-shelf personal computer running an appropriate operating system and/or may be or may include an embedded system running in connection with a personal computer or a relatively larger computing device, such as a minicomputer. The computing device receives signal data in the form of real-time analog or digital inputs or, in some cases, may process data that has already been accumulated and stored and provided on analog or digital tape or otherwise provided as analog or digital data. The data may be provided by band pass filtering sensor data, possibly providing pre-amplification with gain and filtering. In the case of analog data, an analog to digital converter may be used. The computing device is programmed to provide the functionality described herein.

The set of signal quality compliance algorithms **12** includes a baseline noise and EMG signal region selection algorithm **20,** a group of baseline noise (BLN) region signal processing algorithms **100**, a group of EMG signal processing algorithms **110**, a maximum data value algorithm **115**, an SNR computation algorithm **87**, a PSD compliance function **120**, an SNR compliance function **130**, and a performance comparison matrix **140**. In operation, pre-defined signal quality performance metrics **170** for a specified EMG application may be loaded into the set of signal quality compliance algorithms **12**. An analog output **17** of EMG sensor signal data **16**, which includes regions of baseline noise **14** and regions of EMG signal activity **15**, is digitized by an analog to digital converter **18** that outputs digitized EMG sensor signal data **19** that is processed by the set of signal quality compliance algorithms **12.** Calculated results **159** of signal quality assessment from the performance comparison matrix **140** are graphically rendered **160** and presented in a visual display **240** that includes pass/fail text **200**, analog and digital indicators **210**, and instructional text **230**. A separate Boolean value **152** of the signal quality assessment from the performance comparison matrix **140** may be provided as the digital pass/fail output **153** for process control.

The following describe in detail, the process flow for each algorithm in the set of the above mentioned signal quality compliance algorithms **12**.

FIG. 2 details an algorithm **20** for selecting a baseline noise region **38** and an EMG signal activity region **44** of the digitized EMG sensor signal data **19**. The digitized EMG sensor signal data **19** may be divided into a group of data segments **29** by a signal data segmentation function **24** of the baseline noise and EMG signal activity region selection algorithm **20**. A time duration for each individual data segment **26** may be pre-defined by a segment interval metric **172** of a set of performance metrics **171**. An envelope of each data segment **26** may be calculated by an EMG sensor signal data envelope function **30** of a baseline noise and EMG signal activity region selection algorithm **20**, and the mean value of an envelope **31** for each data segment **26** is provided to a minimum signal data segment envelope value function **34**, which determines a minimum envelope value **35** from a set of all the mean values of the envelope **31** for each of the data segments **26**. A baseline noise (BLN) threshold function **36** multiplies a minimum envelope value **35** using a pre-defined multiplier value **173** metric of the set of performance metrics **171** to provide a baseline noise threshold output value **37**. After the determination of the baseline noise threshold output value **37**, the mean value of the envelope **31** of the first segment **27** in the series of signal data segments **29** is selected and compared to the stored BLN threshold output value **37** by a comparison function **40**. The comparison function **40** determines if a mean value of the envelope of the selected data segment **31** is equal to or greater than the BLN threshold output value **37**. If the result of the comparison of the envelope of selected data segment **31** is equal to or greater than the BLN threshold output value **37**, then a command **43** is provided to a selection of EMG signal activity region function **44** to add the respective signal data segment **27** to an EMG signal activity region **49**. If the result of the comparison of the envelop of selected data segment **31** is less than the baseline noise threshold output value **37**, then a command **39** is given to a selection of baseline BLN region function **38** to add the respective signal data segment **27** to a baseline noise region **45**. A segment comparison **40** like that described above is repeated for each of the segments **26** in a series of all of the signal data segments **29**, until the completion of the process for a last signal data segment **28**. In the case where the digitized EMG sensor signal data **19** contains only baseline noise, or only EMG signal activity, the calculated value of the minimum data segment envelope **35** may characterize all data segments above the calculated baseline noise threshold value **37** as EMG signal activity region **44** data segments, and may characterize all signal data segments below the calculated baseline noise threshold value **37** as baseline region **38** data segments. Because there may be only a small difference between the signal data segment envelope values **31** characterized as baseline noise region **38** and the signal data segment envelope values **31** characterized as EMG signal activity region **44**, the SNR algorithm **87** calculation output **122** may produce a value of approximately one, which could be interpreted by the performance metrics comparison matrix **140** as a signal quality assessment failure condition at an output **152**.

An output **45** of the selected baseline noise region of the digitized EMG sensor signal data **19** and the EMG signal activity region **49** of the EMG sensor signal data **19** may be further processed by the respective baseline noise region processing algorithms **100** and EMG signal activity region processing regions **110**. **FIGs. 3-7** illustrate representative examples of a time domain signal data from the output **45** of the selected baseline noise region of the EMG sensor signal data **19** and the EMG signal activity region **49** of the EMG sensor signal data **19**, together with a resultant processed baseline noise region envelope **80**, processed EMG signal activity region envelope **84,** and respective baseline noise frequency domain and EMG signal frequency domain outputs.

The output **45** of the selected baseline noise region of the EMG sensor signal data **19** is processed by the baseline noise region processing algorithms 1**00** that include a motor unit (MU) detection and removal algorithm **50**, an algorithm **80** to determine the BLN signal envelope**,** and a BLN PSD algorithm **88**. **FIG. 3A** shows an output wave shape **42** of the output **45** corresponding to selected baseline noise region of the EMG sensor signal data **19**, uncontaminated by extraneous MU pulses or line interference. As a comparison, **FIG. 3B** shows an output wave shape **41** of the output **45** corresponding to the selected baseline noise region of the EMG sensor signal data **19** contaminated by extraneous MU pulses **48** present in the data. The MU pulses **48** may occur in the output **45** if muscle is not fully relaxed and can lead to an overestimation of a baseline noise envelope amplitude M_{bl} **82** shown in **FIG 5B**.

The MU detection and removal algorithm **50** determines all time segments t_s **175** of output **45** that contain the MU pulse **48** and remove the time segments **175** from the output **45** so that proper estimation of the baseline noise envelope amplitude M_{bl} **82** and baseline PSD magnitude M_{psdlf} **97** can be calculated. The MU detection algorithm **50** determines the number **75** of the time segments t_s **175** of the output **45** that contain the MU pulse **48** and provides the number **75** to the performance metrics comparison matrix **140**. An excessive number of the MU segments **48** in the output **45** triggers a signal quality failure indication at the output **153** and the pass/fail display **200**. **FIG. 4** shows the major functional blocks of the MU detection algorithm **50**. Note that at least some of the MUs may be based on voluntary muscle movement. The input to a baseline noise segmentation function **52** is output **45**, described above. The baseline noise segmentation function segments the data according to the time segments t_s **175** of a set of performance metrics **174**. A first segment **56** in a series of signal data segments **59** is selected and the mean value of an envelope **61** of the selected segment **56** is calculated by a baseline noise segment envelope function **60**. The envelope **61** of the selected segment is compared to a current value **65** stored in a minimum baseline register **64**. The minimum baseline register **64** is initialized to a predefined initial minimum baseline envelope metric **176** of the set of performance metrics **174**. If the envelope **61** for the selected segment is less than the current value **65** stored in the minimum baseline register **64**, the minimum baseline register **64** is updated with the envelope **61** of the selected segment. A BLN threshold function **66** multiplies an updated minimum baseline register value **67** by a predefined metric for allowable baseline noise variation **177** of the set of performance metrics **174**. If mean signal envelope **61** of the selected segment is less than an output of the BLN threshold function **69** at a comparison **70**, then a command **71** is given to the selection of baseline region with no MU pulse function **72** to add the respective signal data segment **56** to the baseline region with MU pulses removed. If the mean signal envelope **61** of the selected segment is greater than the BLN threshold function **69**, the segment is determined to contain a MU pulse and the count of MU pulses removed **75** is incremented by an MU pulse removed counter **74**. The above sequence and comparison **70** is repeated for each of the segments **51** in the series of all of the baseline data segments **59**, until completion of the process for a last baseline data segment **58**. An output **76** of the selected baseline region of the output **45** with the MU pulse **48** removed is provided to the algorithm **80** for detecting BLN envelope, and the BLN PSD algorithm **88.**

FIG. 5A shows a time domain plot of the output **45** processed to remove MU's from the output **76**, and the selected EMG signal activity region with the time domain plot output **46**. **FIG. 5A** also shows a plot of the baseline noise region envelope calculation and a plot of an EMG signal activity region envelope calculation. The algorithm used to determine the envelopes can be the root mean squared value (RMS) or the average rectified value (ARV). The mean magnitude M_{bl} **82** of a baseline envelope value **81** and a mean magnitude M_s **86** of an EMG signal activity envelope value **85** are determined with respect to the zero reference line **83** of the plots of the envelope calculations **80, 84.** The mean magnitude M_{bl} **82** of the output **45** and the calculated envelope output **86** of the selected EMG signal activity region are used to calculate the EMG signal to baseline signal to noise ratio (SNR) using the formula**:**

$$SNR = (\text{EMG region envelope amplitude } M_S)/(\text{ Baseline region envelope amplitude } M_{bl})$$

FIG. 5B shows a plot **89** of the calculated BLN PSD of the output **45** with the selected baseline region processed to remove MU's from the output **76**. **FIG. 5C** shows an EMG PSD plot **91** of the calculated EMG PSD of the time domain plot output **46** of the EMG signal activity region **49** shown in **FIG. 5A**. The algorithm used to determine the PSD of the output **45** and the EMG signal activity region **49** is based on the Welch method of determining the Discrete Fourier Transform. A median frequency $Fmed_s$ **92** parameter of the EMG PSD plot **91** of the EMG signal activity region **49** is also calculated. The calculated median frequency $Fmed_s$ **92** output of the EMG PSD signal processing algorithm is provided to the PSD compliance function **120** and the performance metrics comparison matrix **140,** and is used to characterize the frequency content of the EMG signal activity region **49** of the EMG sensor signal data output **19.** Although the median frequency $Fmed_s$ **92** parameter may be used, alternative parameters such as mean frequency can be used to characterize the spectrum of the EMG signal activity region **49**.

FIGs. 6A-6B and **7A-7B** illustrate a process for determining a magnitude of power line contamination in the output **76** of selected baseline noise region **45**. **FIG. 6A** shows a time domain plot **276** of the selected baseline noise region **45** that is uncontaminated by power line interference. A plot of the calculated BLN PSD of the uncontaminated selected baseline region **45** is shown in **FIG. 6B**, together with an expanded view of the plot centered on a frequency region of a power line frequency **94**. A PSD magnitude M_{psdlf} at a frequency region of the power line frequency **94** of the plot is comparable to an average PSD magnitude M_{psdbl} in a frequency region adjacent to the frequency region of the power line frequency **94**. As a comparison, **FIG. 7A** shows a time domain plot **276'** of the selected baseline noise region **45** that is contaminated by power line interference **47**. A plot of the calculated BLN PSD of the contaminated selected baseline noise region **45** is shown in **FIG. 7B** together with an expanded view of the plot centered on a frequency region of the power line frequency **94**. A PSD magnitude M_{psdlf} at the frequency region of the power line frequency **94** of plot shows an increase in amplitude **99** that is higher than an average PSD magnitude M_{psdbl} in the frequency region adjacent to the frequency region of the power line frequency **94.** A calculated BLN PSD output of the selected baseline noise region **45** is provided to the performance metrics comparison matrix **140**. An excessive PSD magnitude value M_{psdlf} at the frequency region of the power line frequency **94** in the baseline region signal data **45** triggers a signal quality failure indication at the output **153** and the pass/fail display **200**.

FIG. 8 shows a time domain plot of the selected EMG signal activity region **49** that is contaminated by occurrences **117** of data samples which are at a maximum positive value **118** and at a maximum negative value **119** from the digital output **19** of the A/D convertor **18**. This condition is termed “clipping” and results from analog output **17** signal levels which exceed the dynamic range of the A/D converter **18**. A maximum data value algorithm **115** calculates a maximum absolute data value **114** from the digital output **19** of the A/D converter **18** and provides the maximum absolute data value **114** to the performance metrics comparison matrix **140**. An excessive maximum absolute data value **114** from the digital output **19** of the A/D converter **18** triggers a signal quality failure indication at the output **153** and the pass/fail display **200.**

As further illustrated in **FIG. 1**, the set of signal quality compliance algorithms **12** include an SNR compliance function **130** and a PSD compliance function **120.** The functions **120**, **130** provide the ability to modify maximum acceptable values for magnitude of the selected baseline noise region BLN envelope mean magnitude M_{bl} **82,** and the PSD magnitude M_{psdlf} **97** of the power line frequency **94** determined by BLN PSD algorithm **88**.

In many applications, EMG sensor signals **16** with a high SNR value, can tolerate a greater degree of baseline noise region envelope mean magnitude M_{bl} **82**, and the signal quality acceptance criteria for baseline noise envelope mean magnitude M_{bl} **82** can be increased. The SNR compliance function **130** uses pre-defined performance metrics values **179** from the set of pre-defined signal quality performance metrics **170** which define the relationship between baseline noise envelope value **82** and SNR value **122**. The output **135** of the SNR compliance function **130** is provided to the performance metrics comparison matrix **140** to adjust the pre-defined limit for baseline noise based on SNR **122**.

Similarly, EMG sensor signals **16** with a high SNR value **122** and/or a high PSD $Fmed_{psd}$ output value **92** can tolerate a greater PSD magnitude M_{psdlf} **97** at the frequency region of the power line interference frequency **94** in the calculated BLN PSD of the selected baseline noise region signal data **45**, and the signal quality acceptance criteria for power line interference value **97** can be increased. This is possible because an $Fmed_{psd}$ value **92** greater than the PSD magnitude M_{psdlf} **97** at the frequency region of the power line interference frequency **94** allows for the implementation of a high pass or notch filtering reducing its percentage of line interference contamination to an acceptable level, especially for EMG sensor signals **16** with a high SNR **122**. The PSD compliance function **120** uses pre-defined performance metrics values **178** from the pre-defined signal quality performance metrics **170** which define the relationship between the calculated PSD $Fmed_{psd}$ value **92**, the calculated SNR value **122**, and the calculated PSD magnitude M_{psdlf} **97** at the frequency region of the power line interference frequency **94.** The output **125** of the PSD compliance function **120** is provided to the performance metrics comparison matrix **140** to adjust the pre-defined limit for the calculated PSD magnitude M_{psdlf} **97** based on calculated SNR **122** and calculated $Fmed_{psd}$ value **92**.

The performance metrics comparison matrix **140** shown in **FIG. 1** performs a numerical comparison on each of the calculated output values of the baseline region processing algorithms **100**, the EMG signal activity region processing algorithms **110**, the maximum data value algorithm **115**, the SNR calculation value **122**, and the PSD compliance **125** and SNR compliance **130** function values with respect to their pre-defined acceptable performance metrics values **180**. **FIG. 9** shows the major functional blocks of the performance metrics comparison matrix **140.** Each calculated output **142** in the group of calculated outputs **146** is compared with its respective predefined performance metric **180** in the performance metrics comparison matrix **140** using a separate binary pass/fail comparison function **141**. For each calculated output **142**, the comparison function **141** provides the binary value 1 at the YES output **147** for a PASS result and provides the binary value 1 at the NO output **148** for a FAIL result. The YES binary output **147** of each separate pass/fail comparison function **141** is provided to a multiple input Boolean AND gate **151**. The binary output **152** of the multiple input Boolean AND gate **151** is a binary value 1 if each YES binary output **147** of each separate pass/fail comparison function **141** is a binary value 1 indicating the result of the signal quality assessment has passed. If any YES binary output **147** of each separate pass/fail comparison function **141** is a binary value 0, then binary value of the Boolean AND gate **151** is 0 indicating the result of the signal quality assessment has failed. The output of Boolean AND gate **152** is provided to the digital Pass/Fail output **153** and the display output rendering function **160**. The results **159** of the performance metrics comparison matrix **140** consisting of the Boolean results of the numerical comparison **152** together with the calculated value of the magnitude of the baseline noise envelope **82**, the calculated values of the scaled, calculated PSD magnitude **97** at the frequency region of the power line interference frequency **94**, and the calculated SNR value **122** are rendered for output display **160**. When all of the results **159** of all comparisons of the calculated output values meet or exceed the pre-defined acceptable performance metrics values **180,** a Boolean 1 PASS output **152** and an "OK to Proceed" indication **205** on the graphical display **200** will be generated. When any of the results **159** of all comparisons of the calculated output values do not meet or exceed the pre-defined acceptable performance metrics values **180**, a Boolean 0 FAIL output **152** and a FAILED indication **205** on the graphical display **200** will be generated.

FIG. 10 shows a screen shot of the visual display **240** for the presentation of the results for a signal quality assessment which met or exceeded all pre-defined performance metrics. The display **240** is comprised a Pass/Fail display result region 2**00**, a calculated signal quality results region **210**, and an instructional text region **230**. During the initial presentation of the results display **240**, for a signal quality assessment which met or exceeded all pre-defined performance metrics, only the Pass/Fail display result region 2**00** is displayed. The calculated signal quality results region **210** and the instructional text region **230** are hidden from view, unless the "Always show details" check box **191** is selected active as is shown in this illustration. Alternatively, the calculated signal quality results region **210**, and the instructional text region **230** can be made visible as a result of the operator selecting the control button **208**. The Pass/Fail display result region **200** has a signal quality result text message output **205** indicating "Signal Check

Complete" and that it is "OK to Proceed". The Pass/Fail display result region **200** is filled with the color green **207** to indicate the signal quality assessment result met the pre-defined performance metrics **180** for signal quality. The "Continue" control button **209** closes the display window **240**. The calculated signal quality results region **210** of the display **240** presents analog meter displays **211** consisting of an analog meter display of the baseline noise value **212**, an analog meter display of the scaled power line interference value **213**, and an analog meter display of the SNR value **214**. Each of the analog meter displays **211** has region **215** filled with the color green to indicate the range of output values which fall within the pre-defined acceptable performance metrics values **180** and has region **216** filled with the color red to indicate the range of output values which fall outside the pre-defined acceptable performance metrics values **180**. The calculated signal quality results region **210** also presents digital numerical displays 217 consisting of a digital display of the baseline noise value **218**, a digital display of the scaled power line interference value **219**, and a digital display of the SNR value **220**. Each of the digital displays **217** has a region filled with the color green **221** to indicate the range of output values fall within the pre-defined acceptable performance metrics values **180**. The instructional text region **230** of the display **240** contains a text block **232** with an instructional message **231** indicating that the SNR value is sufficient.

FIG. 11 shows a screen shot of the visual display **240** shown in **FIG. 10** representing the results for a signal quality assessment which failed to meet one or more of the pre-defined performance metrics **180**. When the results for a signal quality assessment fail to meet one or more of the pre-defined performance metrics **180,** the Pass/Fail display result region **200**, a calculated signal quality results region **210**, and an instructional text region **230** of the display **240** are all simultaneously displayed. The Pass/Fail display result region 2**00** has a signal quality result text message output **205** indicating "Signal Check Complete" and that it "Failed". The Pass/Fail display result region 2**00** is filled with the color red **206** to indicate a negative signal quality assessment result. Each of the digital displays **217** has region filled with the color green **221** to indicate the range of output values which fall within the pre-defined acceptable performance metrics values **180** and filled with the color red **223** to indicate the range of output values which fall outside the limits of the pre-defined acceptable performance metrics values **180**. In this example, the digital display for line interference **219** has its region filled with the color red **223** indicating that the predefined metric **180** for line interference **219** has been exceeded. The instructional text region **230** of the display **240** contains a text block **232** with an appropriate instructional message **234** for addressing and correcting the failure conditions.

The process for assessing the signal quality of an EMG sensor signal data output channel described herein may be applied as a stand-alone process, or can be included as a signal processing component within a group of data acquisition and processing components used during the data acquisition function of an electromyographic application. The process described herein can also be applied as a stand-alone process, or can be included as a signal processing component within a group of signal processing components forming the data analysis function of an electromyographic application.

Another embodiment of a system **311** for assessing signal quality of a plurality of EMG sensor signal data output channels includes a set of signal quality compliance algorithms **312**, generated visual displays of graphics and text **313**, and a digital pass/fail result output **453** as illustrated in the system block diagram of **FIG. 12**. The system **311** provides for multi-channel input. As with the system **11**, described above, the sensor data may be from a single differential EMG sensor or from a double differential EMG sensor placed on the skin of a subject. The system **311** may be implemented using hardware (e.g., off-the shelf computer processing hardware), software (e.g., a computer program written in an appropriate language to provide the functionality described herein), or some combination thereof. In an embodiment herein, the system **311** may be implemented using a computing device such as an off-the-shelf personal computer running an appropriate operating system and/or may be or may include an embedded system running in connection with a personal computer or a relatively larger computing device, such as a minicomputer. The computing device receives signal data in the form of real-time analog or digital inputs or, in some cases, may process data that has already been accumulated and stored and provided on analog or digital tape or otherwise provided as analog or digital data. The data may be provided by band pass filtering sensor data, possibly providing pre-amplification with gain and filtering. In the case of digital data, an analog to digital converter may be used. The computing device is programmed to provide the functionality described herein.

The following is a general overview of the major functional blocks of the process according to the system **311** shown in **FIG. 12**. The set of signal quality compliance algorithms **312** includes a multi-input baseline noise and EMG signal activity region selection algorithm **320**, a group of multi-input baseline noise region signal processing algorithms **400**, a group of multi-input EMG signal activity region processing algorithms **410**, a multi-input maximum data value algorithm **415**, a multi-input baseline region PSD combination algorithm **416**, a multi-input baseline region envelope combination algorithm **417**, a multi-input EMG signal activity region PSD combination algorithm **418**, a multi-input SNR computation algorithm **419**, a PSD compliance function **420**, an SNR compliance function **430**, and a performance metrics comparison matrix **440**. In operation, pre-defined signal quality performance metrics **470** for a specified EMG application may be loaded into the set of signal quality compliance algorithms **312**. The EMG sensor signal data channels **316** to be proceeded for signal quality can originate from multiple separate, independent sensor technologies, individual sensor array technologies with multiple signal outputs, or a combination of both technologies. The analog output **317** of each of the multiple EMG sensor signal data channels **314** is digitized by an analog to digital convertor **318** whose multi-channel digital output **319** is processed by the set of signal quality compliance algorithms **312.** The calculated results **459** of the signal quality assessment from the performance comparison matrix **440** are graphically rendered **460** and presented in a visual display **540** consisting of pass/fail text **400**, analog and digital indicators **410**, and instructional text **430**. A separate Boolean value **452** of the signal quality assessment from the performance comparison matrix **440** is provided as digital pass/fail output **453** for process control.

The following describes in detail a process flow for each algorithm in the set of the above mentioned signal quality compliance algorithms **312**. **FIG. 13** shows a shaded block diagram of the algorithm **320** used for selecting the multi-channel baseline noise region **345** and the multi-channel EMG signal activity region **349** of the digitized sensor signal data **319**. For each digitized sensor signal channel **319** of the multi-channel EMG sensor signal data **347**, the following sequence of steps is performed to select the regions of baseline noise **345** and to select the regions of EMG signal activity **349**. The digitized signal data **319** is divided into data segments **329** by the multi-channel signal data segmentation function **324** of the multi-channel baseline noise and EMG signal activity region selection algorithm **320**. The time duration for each data segment is pre-defined by the segment interval metric **472** of the set of performance metrics **471**. The envelope of each data segment **331** is calculated by the signal data envelope function **330** of the baseline noise and EMG signal activity region selection algorithm **320**, and the mean value of the envelope **331** for each data segment **329** is provided to the minimum signal data segment envelope value function **334** which determines the minimum envelope value **335** from the set of all the mean values of the envelope segments **331**. The baseline BLN threshold function **336** multiplies the minimum envelope value **335** by a pre-defined multiplier value **473** metric of the set of performance metrics **471** to provide a baseline noise threshold output value **337**. After the determination baseline noise threshold output value **337**, the mean value of the envelope **331** of the first segment in the series of signal data segments **329** is selected and compared to the stored baseline noise threshold output value **337** by the comparison function **340**. The comparison function **340** determines if the mean value of the envelope of the selected data segment **331** is equal to or greater than the baseline noise threshold output value **337**. If the result of the comparison of the envelop of selected data segment **331** is equal to or greater than the baseline noise threshold output value **337**, then a command **343** is given to the selection of EMG signal activity region function **344** to add the respective signal data segment **329** to the EMG signal activity region **349**. If the result of the comparison of the envelop of selected data segment **331** is less than the baseline noise threshold output value **337**, then a command **339** is given to the selection of baseline region function **338** to add the respective signal data segment **329** to the baseline region **345**. For each the channels **347**, the above comparison **340** is repeated for each segment in the series of all of the EMG sensor signal data segments **329**, until the completion of the process for the last signal data segment, and the process **320** repeated until completion of the last channel **342**.

As shown in **FIG. 12**, the time domain signal data from each channel of the multi-channel outputs **345** of the selected baseline region of the EMG sensor signal data **338** and the multi-channel outputs **349** of the selected EMG signal activity region of the EMG sensor signal data **344** are further processed by their respective group of multi-channel baseline region processing algorithms **400** and group of multi-channel EMG signal activity region processing algorithms **410**. The group of multi-channel baseline region processing algorithms **400** is comprised of a multi-channel motor unit (MU) detection and removal algorithm **350**, a multi-channel algorithm to determine the baseline noise signal BLN envelope **380,** and a multi-channel BLN PSD algorithm **388.** The group of multi-channel EMG signal activity region processing algorithms **410** is comprised of a multi-channel EMG PSD algorithm **390**, and a multi-channel algorithm to determine the EMG signal activity envelope **384.** The function of the multi-channel MU detection and removal algorithm **350** of the baseline region processing algorithms **400** is to determine all the presence of MU pulses in each the selected baseline regions of the respective signal data channels **345** remove these MU pulses from the baseline regions of the respective signal data channels **345** so that proper estimation of baseline noise envelope amplitude **382** and BLN PSD amplitude **397** for each respective channel can be calculated. The MU detection and removal algorithm **350** determines the number of MU pulses **375** in the baseline regions of the respective signal data channels **345** and provides this number for each respective output to the performance metrics comparison matrix **440**. Note that at least some of the MUs may be a result of voluntary muscle movement. An excessive number of MU pulses **375** in the baseline region signal data **345** compared to the pre-defined metric for acceptable number of MU segments **480** will trigger a signal quality failure indication on the pass/fail output **453** and on the visual displays **540**. The multi-channel output **376** of the selected baseline regions of the respective signal data channels with the respective MU pulses removed is provided to the multi-channel baseline noise signal BLN envelope algorithm **380,** and the multi-channel BLN PSD algorithm **388.** The algorithm used to determine the multi-channel envelopes **380** of the selected baseline noise regions with the respective MU pulses removed **376**, and multi-channel envelopes **384** of selected EMG signal regions **349** can be the root-mean-squared value (RMS) or the average rectified value (ARV) calculation. The magnitude of each of the calculated multi-channel baseline noise region envelope values **382** and the magnitude of each of the calculated multi-channel the EMG signal activity envelope values **386** are used to calculate the multi-channel EMG signal to baseline noise SNR **387** of each of the respective channels. The algorithm used to determine the multi-channel PSD of the selected baseline **388** and multi-channel PSD of the selected EMG signal activity **390** regions is based on the Welch method of determining the Discrete Fourier Transform. A multi-channel BLN PSD algorithm **388** is used to calculate the magnitude of power line contamination at the frequency regions of the power line frequency component in the output of the power spectrum **388** of the selected baseline region **376** of each of the respective channels. The value of the calculated multi-channel output **397** of each of the respective channels of the multi-channel PSD algorithm **388** is provided to the performance metrics comparison matrix **440** and the BLN PSD combination algorithm **416**. A multi-channel EMG PSD algorithm **390** is used to calculate the median frequency **392** output of the power spectrum of the selected EMG signal activity region **349** of each EMG sensor signal data channels **316**. Although the median frequency parameter may be used, alternative parameters such as mean frequency can be used to characterize the EMG signal activity region **349** spectrum. The median frequency output **392** of each channel is provided to the EMG PSD combination algorithm **418**. For each of the EMG sensor data channels **316**, the maximum data value algorithm **415** calculates the maximum absolute data value **414** from the digital output **319** of the A/D converter **318** and provides this output **414** to the performance metrics comparison matrix **440**. An excessive maximum absolute data value **414** from the digital output 3**19** of the A/D converter 3**18** will trigger a signal quality failure indication at the digital output **453** and the pass/fail displays **540.**

As further illustrated in **FIG. 12**, the set of signal quality compliance algorithms **312** in the system **311** includes a BLN PSD combination algorithm **416**, a BLN envelope combination algorithm **417**, an EMG signal activity PSD combination algorithm **418**, an SNR combination algorithm **419**, a PSD compliance function **420**, and an SNR compliance function **430**.

In addition to the ability of the performance metrics comparison matrix **440** to compare the processed values obtained from each individual channel output, the signal quality assessment process **312** can combine the respective outputs of the multi-channel baseline signal BLN PSD algorithm **388**, the multi-channel baseline signal envelope algorithm **380**, the multi-channel EMG signal activity PSD algorithm **390**, and the multi-channel SNR algorithm **387** into a single representative output value for each algorithm. This feature of the system described herein is useful for characterizing the overall signal quality performance from array sensors whose multiple signal channels share a common detection region and share common signal amplitude and frequency attributes.

FIG 14 shows a block diagram of a generic implementation of a multi-channel combination algorithm **360** used to illustrate the approach and implementation of the common functional elements utilized by the baseline BLN PSD combination algorithm **416**, the baseline envelope combination algorithm **417**, the EMG signal activity PSD combination algorithm **418**, and the SNR combination algorithm **419**. The inputs to the generic algorithm **360** represent the respective calculated outputs of each of the channels from the multi-channel baseline PSD algorithm **397**, the multi-channel baseline envelope algorithm **382**, the multi-channel EMG activity PSD algorithm **392**, and the multi-channel SNR algorithm **422**. The common shared functional elements of the generic combination algorithm **360** consist of a weighted average function **356**, a maximum value function **357**, a minimum value function **358**, and a modality function **359** that determines the selected function output **362, 363, 361,** and **364**. The features of the generic combination algorithm **360** as they relate to each implementation are described in the following sections.

The baseline BLN PSD combination algorithm **416** calculates an output value that can be the weighted average of the magnitude of power line contamination at the frequency regions of the power line frequency component in the output signal **397** of each of the channels, the minimum value of the magnitude of power line contamination at the frequency regions of the power line frequency component in the output signal **397** of each of the channels, or the maximum value of the magnitude of power line contamination at the frequency regions of the power line frequency component in the output signal **397** of each of the channels. The type of calculation modality selected for combining magnitude of power line contamination at the frequency regions of the power line frequency component in the output signal **397** of each of the channels, is specified by the set of pre-defined performance metrics **475** and is based on type of sensor data. For individual EMG channels obtained from multiple sensors, the minimum value calculating modality **358** would typically be selected to determine the combined magnitude of power line contamination at the frequency regions of the power line frequency component **397** in the output frequency spectrum **397**. For an array sensor with multiple output channels, the weighted average value calculating modality, or the minimum value calculating modality would typically be selected. The output **361** of the PSD combination algorithm is provided to the performance metrics comparison matrix algorithm **440**. The baseline noise BLN envelope combination algorithm **417** calculates an output value that can be the weighted average of the magnitude of baseline noise envelope **382** of each of the channels, the minimum value of the magnitude of baseline noise envelope **382** of each of the channels, or the maximum value of the magnitude of the magnitude of baseline noise envelope **382** of each of the channels. The type of calculation modality selected for combining the magnitude of baseline noise envelope **382** of each of the channels, is specified by the set of pre-defined performance metrics **476** and is based on type of sensor data. For individual EMG channels obtained from multiple sensors, the minimum value calculating modality **358** would typically be selected to determine the combined magnitude of the baseline envelope **382** of each of the channels. For an array sensor with multiple output channels, the weighted average value calculating modality **356**, or the minimum value calculating modality **358** would typically be selected. The output **362** of the baseline envelope combination algorithm **417** is provided to the performance metrics comparison matrix algorithm **440**. The EMG signal activity PSD combination algorithm **418** calculates an output value that can be the weighted average of the median frequency output **392** of each of the channels, the minimum value of the median frequency output **392** of each of the channels, or the maximum value of the median frequency output **392** of each of the channels. The type of calculation modality selected for combining the median frequency output **392** of each channel of the EMG activity PSD algorithm **390** is specified by the set of pre-defined performance metrics **477** and is based on type of sensor data. For individual EMG channels obtained from multiple sensors, the minimum value calculating modality **358** would typically be selected to determine the magnitude of the combined median frequency output value **363**. For an array sensor with multiple output channels the weighted average value calculating modality **356**, or the minimum value calculating modality **358** would typically be selected. The output **363** of the PSD combination algorithm is provided is provided to the PSD compliance function **420** and to the performance metrics comparison matrix algorithm **440**. The SNR combination algorithm **419** calculates an output value that can be the weighted average of the SNR value **356** of each of the channels, the minimum value of the SNR value **358** of each of the channels, or the maximum value of the of the SNR value **357** of each of the channels. The type of calculation modality selected for combining the SNR value **422** of each of the channels, is specified by the set of pre-defined performance metrics **481** and is based on type of sensor data. For individual EMG channels obtained from multiple sensors, the minimum value calculating modality would typically be selected to determine the combined SNR value **364**. For an array sensor with multiple output channels, the weighted average value calculating modality **356**, or the minimum value calculating modality **358** would typically be selected. The output **364** of the SNR combination algorithm is provided to the PSD compliance function **420**, the SNR compliance function **430** and to the performance metrics comparison matrix algorithm **440**.

The set of signal quality compliance algorithms **312** in the system **311** includes a PSD compliance function **420**, and an SNR compliance function **430**. The functions **420**, **430** provide an ability to modify maximum acceptable values for magnitude of the selected baseline noise envelope **362**, **382,** and the magnitude of the power line frequency **361**, **397** of the selected baseline PSD output **388**.

In many applications, EMG sensor signals **316** with a high SNR value **422**, can tolerate a greater degree of baseline noise envelope value **382**, and the signal quality acceptance criteria for baseline envelope value **382** can be increased. The SNR compliance function **430** uses pre-defined performance metrics values **479** from the set of pre-defined performance metrics values **470** which define the relationship between combined baseline envelope value **362** and the combined SNR value **364**. The output **435** of the SNR compliance function **430** is provided to the performance metrics comparison matrix **440** to adjust the pre-defined limit for the combined baseline envelope **361** based on combined SNR output **364**.

Similarly, EMG signals **316** with a high SNR value **422** and/or a EMG PSD Fmed value **392** can tolerate a greater BLN PSD magnitude **397** at the frequency region of the power line interference frequency in the calculated PSD output **397** of the selected baseline noise region signal data **376**, and the signal quality acceptance criteria for power line interference value can be increased. This is possible because an EMG PSD Fmed value **392** greater than the BLN PSD magnitude **397** at the frequency region of the power line interference frequency allows for the implementation of a high pass or notch filtering, reducing its percentage of line interference contamination to an acceptable level, especially for EMG signals **316** with a high SNR **422**. The PSD compliance function **420** uses pre-defined performance metrics values **478** from the set of pre-defined performance metrics values **470** which define the relationship between the combined EMG PSD Fmed value **363**, the combined SNR value **364**, and the combined BLN PSD magnitude **361** at the frequency region of the power line interference frequency. The output **425** of the PSD compliance function **420** is provided to the performance metrics comparison matrix

440 to adjust the pre-defined limit for the calculated combined BLN PSD magnitude **361** based on calculated combined SNR **364** and calculated combined EMG PSD Fmed value **363**.

For each channel **314** of the multi-channel EMG sensor signal data channels **316**, the performance metrics comparison matrix **440** performs a numerical comparison on each of the calculated output values of the baseline region processing algorithms **400**, the EMG signal activity region processing algorithms **410**, the SNR calculation value **422**, the PSD compliance **425,** and SNR compliance **435** function values with respect to their pre-defined acceptable performance metrics values **480**. The output **459** the performance metrics comparison matrix **440** consisting of the Boolean results of the numerical comparison **452** together with the calculated value of the magnitude of the baseline noise envelope **382**, the calculated values of the scaled, calculated PSD magnitude **397** at the frequency region of the power line interference frequency, and the calculated SNR value **422** are rendered for output display **460**.

When all comparisons of the calculated output values of the baseline region processing algorithms **400**, the EMG signal region processing algorithms **410**, the SNR calculation value **422**, and the PSD compliance **425** and SNR compliance **430** function values with respect to their pre-defined acceptable performance metrics values **480** meet or exceed the pre-defined acceptable performance metrics values **480,** a Boolean 1 (Pass) output **452**, and a “OK to Proceed” indication **505** on the graphical displays **540** will be generated. When any of the comparisons of the calculated output values of the baseline region processing algorithms **400**, the EMG signal region processing algorithms **410**, the SNR calculation value **422**, and the PSD compliance **425** and SNR compliance **430** function values with respect to their pre-defined acceptable performance metrics values **480** does not meet or exceed the pre-defined acceptable performance metrics values **480**, a Boolean 0 (Fail) output **452** and a “Failed” indication **505** on the graphical display **540** will be generated.

FIG. 15 shows a screen shot of the visual display **540** for the presentation of the results for a multi-channel EMG sensor signal quality assessment which met or exceeded all pre-defined performance metrics. The display **540** is comprised a Pass/Fail display result region **500**, a calculated signal quality results region **510**, and an instructional text region **530**. During the initial presentation of the display **540**, only the Pass/Fail display result region **500** is displayed with the calculated signal quality results region **510**, and the instructional text region **530** hidden from view, unless the "Always show details" check box **533** is selected active as is shown in this illustration. Alternatively, the calculated signal quality results region **510**, and the instructional text region **539** can be made visible as a result of the operator pressing the show details control button **508**. The Pass/Fail display result region **500** has a signal quality result text message output **505** indicating "Signal Check Complete" and that it is "OK to Proceed". The Pass/Fail display result region **500** is filled with the color green **507** to indicate the signal quality assessment result met the pre-defined performance metrics **480** for signal quality. The desired channel **395** of signal quality results for each channel **314** of the multi-channel EMG sensor channels **316** can be selected for viewing **394** in using the channel up/down control **396**. The results for the selected channel **395** are viewed in the calculated signal quality results region **510** of the display. The calculated signal quality results region **510** of the display **540** presents analog meter displays **511** consisting of an analog meter display of the baseline noise value **512**, an analog meter display of the power line interference value **513**, and an analog meter display of the SNR value **514**. The calculated signal quality results region **510** also presents digital numerical displays **517** consisting of a digital display of the baseline noise value **518**, a digital display of the power line interference value **519**, and a digital display of the SNR value **520**. Each of the digital displays **517** has region filled with the color green **521** to indicate the range of output values fall within the pre-defined acceptable performance metrics values **480**. The instructional text region **530** of the display **540** contains a text block **532** with instructional message **531**.

FIG. 16 shows a screen shot of the visual display **540** shown in **FIG. 15** representing the results for a multi-channel EMG sensor signal quality assessment which failed to meet one or more of the pre-defined performance metrics **480**. When the results for a signal quality assessment fail to meet one or more of the pre-defined performance metrics **480,** the Pass/Fail display result region **500**, the calculated signal quality results region **510**, and the instructional text region **530** of the display **540** are all simultaneously displayed. The Pass/Fail display result region **500** has a signal quality result text message output **505** indicating "Signal Check Complete" and that it "Failed". The Pass/Fail display result region **500** is filled with the color red **506** to indicate a negative signal quality assessment result. The results for the first channel that failed to meet one or more of the pre-defined performance metrics **480** are viewed in the calculated signal quality results region **510** of the display. Signal quality results for each additional channel **314** of the multi-channel EMG sensor channels **316** can be selected for viewing **394** in using the channel up/down control **396**. The results for the selected channel **395** are viewed in the calculated signal quality results region **510** of the display. Each of the digital displays **517** has region filled with the color green **521** to indicate the range of output values which fall within the pre-defined acceptable performance metrics values **480** and filled with the color red **523** to indicate the range of output values which fall outside the limits of the pre-defined acceptable performance metrics values **480**. In this example, the digital display for line interference 519 has its region filled with the color red **523** indicating that the predefined metric for line interference has been exceeded. The instructional text region **530** of the display **540** contains a text block **532** with an appropriate instructional message **531** for addressing and correcting the failure conditions.

According to the system described herein, the process for assessing the signal quality of a plurality of EMG sensor signal data output channels in the system **311** can be applied as a stand-alone process, or can be included as a signal processing component within a group of data acquisition and processing components used during the data acquisition function of an electromyographic application. The mechanism illustrated by the system **311** may also be applied as a stand-alone process, or can be included as a signal processing component within a group of signal processing components forming the data analysis function of an electromyographic application.

Various embodiments discussed herein may be combined with each other in appropriate combinations in connection with the system described herein. Additionally, in some instances, the order of steps of described flow processing may be modified, where appropriate. Subsequently, elements and areas of screen described in screen layouts may vary from the illustrations presented herein. Further, various aspects of the system described herein may be implemented using software, hardware, a combination of software and hardware and/or other computer-implemented modules or devices having the described features and performing the described functions.

Software implementations of the system described herein may include executable code that is stored in a computer readable medium and executed by one or more processors. The computer readable medium may be non-transitory and include a computer hard drive, ROM, RAM, flash memory, portable computer storage media such as a CD-ROM, a DVD-ROM, a flash drive, an SD card and/or other drive with, for example, a universal serial bus (USB) interface, and/or any other appropriate tangible or non-transitory computer readable medium or computer memory on which executable code may be stored and executed by a processor. The system described herein may be used in connection with any appropriate operating system.

Other embodiments of the invention will be apparent to those skilled in the art from a consideration of the specification or practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. A method for evaluating at least one of a plurality of EMG sensor signal data outputs, comprising:

determining regions of baseline noise, line interference, and summated motor unit action potential components for each of the plurality of the signal data outputs;

arithmetically combining corresponding time and frequency domain parameters of each region into parameters to provide a set of calculated electromyographic signal performance metrics that include a baseline noise value, a magnitude and power spectra of a summated motor unit action potential components, a line interference spectra value, an EMG signal to baseline noise ratio, and a maximum data value;

visually displaying the calculated electromyographic signal performance metrics;

comparing the calculated electromyographic signal performance metrics with a set of pre-defined electromyographic signal performance metrics values;

providing an output indicating an acceptable signal quality result in response to all of the calculated performance metrics meeting the pre-defined electromyographic signal performance metrics; and

providing an output indicating a non-acceptable signal quality result in response to at least one of the calculated performance metrics not meeting the pre-defined performance metrics.

2. A method according to claim **1**, wherein there is one EMG sensor signal data output.

3. A method according to claim **1**, wherein there is more than one EMG sensor signal data output.

4. A method according to claim **1**, wherein the set of pre-defined electromyographic signal performance metrics are determined according to performance requirements of a selected EMG application, and include an allowable number of segments from a baseline region containing motor unit action potentials, an allowable value for the EMG signal to baseline noise ratio, an allowable maximum value for a signal data output, values of coefficients of variables used in mathematical functions that arithmetically combine a plurality of individual parameter values into single respective parameter values, values of coefficients of variables used in a mathematical function that calculates an allowable baseline noise value based on the EMG signal to baseline noise ratio, and values of coefficients of variables used in a mathematical function that calculates an allowable value for spectral components of the line interference based on a calculated value of the EMG signal to baseline noise ratio and a calculated value of the summated motor unit action potential components power spectra.

5. A method according to claim **1**, wherein determination of the summated motor unit action potential component includes an algorithm designed to identify data segments containing motor unit action potentials and calculate a summated motor unit action potential components region signal envelope and wherein the magnitude of the summated motor unit action potential components region signal envelope is included in the calculated performance metrics.

6. A method according to claim **1**, wherein determination of the line interference component includes an algorithm designed to calculate a power spectral density function of the baseline noise and to identify magnitudes of 50 Hz, 60 Hz, and associated harmonic components of the EMG sensor signal data and wherein the magnitudes of the components of line interference are included in the calculated performance metrics.

7. A method according to claim **1**, wherein determining regions of baseline noise include an algorithm designed to divide a signal envelope of the summated motor unit action potential component by a baseline noise region signal envelope and provide a result thereof as the signal to baseline noise ratio and wherein a magnitude of the signal to baseline noise ratio is included in the calculated performance metrics.

8. A method according to claim **1**, wherein determination of the maximum data value includes an algorithm designed to calculate a maximum absolute value of the data and wherein the maximum absolute value is included in the calculated performance metrics.

9. A method according to claim **1**, wherein the calculated performance metrics include a mean value of a magnitude of a baseline noise region signal envelope, a mean value of a line interference spectra magnitude, and a mean value of the signal to baseline noise ratio, wherein each of the mean values is calculated from a plurality of individual parameter values.

10. A method according to claim **1**, wherein an allowable value for a baseline noise signal envelope is calculated as a function of a pre-defined value of allowable baseline noise and the calculated signal to noise ratio.

11. A method according to claim **1**, wherein an allowable value for the spectral components of the line interference is calculated as a function of a pre-defined value of allowable spectral components of the line interference and the calculated signal to noise ratio.

12. A method according to claim **1**, wherein a compliance state of a recorded signal quality result output is provided as an accessible digital control output available for integration with other hardware and software processes.

13. A method according to claim **1**, wherein a visual graphic display presentation of results output are expanded by user activated control, to include presentation of calculated parameter values of the baseline noise, line interference, and signal to baseline noise ratio, using a combination of digital and analog indicators, each marked with a value of the pre-defined performance metric for respective output parameters thereof, wherein the visual graphic display presentation includes presentation of additional descriptive text blocks associated with each respective calculated parameter value output.

14. A method according to claim **13**, wherein the visual graphic display presentation of results output is automatically expanded to include presentation of calculated parameter values of the baseline noise magnitude, line interference magnitude and signal to baseline noise magnitude using a combination of digital and analog indicators, each marked with the value of the pre-defined performance metric for respective output parameters thereof.

15. A method according to claim **14**, wherein the visual graphic display includes presentation of additional descriptive text blocks associated with each respective calculated parameter value output having text content based on context determined by a state of compliance with a set of pre-defined performance metrics values.

16. A method according to claim **15**, wherein the descriptive text blocks provide instructions for addressing and correcting conditions of non-compliance of each calculated parameter value output with respect to the set of pre-defined performance metrics values.

17. Computer software, provided in a non-transitory computer-readable medium, that evaluates at least one of a plurality of EMG sensor signal data outputs, the software comprising:

executable code that determines regions of baseline noise, line interference, and summated motor unit action potential components for each of the plurality of the signal data outputs;

executable code that arithmetically combines corresponding time and frequency domain parameters of each region into parameters to provide a set of calculated electromyographic signal performance metrics that includes a baseline noise value, a magnitude and power spectra of a summated motor unit action potential components, a line interference spectra value, an EMG signal to baseline noise ratio, and a maximum data value;

executable code that visually displays the calculated electromyographic signal performance metrics;

executable code that compares the calculated electromyographic signal performance metrics with a set of pre-defined electromyographic signal performance metrics values;

executable code that provides an output indicating an acceptable signal quality result in response to all of the calculated performance metrics meeting the pre-defined electromyographic signal performance metrics; and

executable code that provides an output indicating a non-acceptable signal quality result in response to at least one of the calculated performance metrics not meeting the pre-defined performance metrics.

18. Computer software according to claim **17**, wherein the set of pre-defined electromyographic signal performance metrics are determined according to performance requirements of a selected EMG application, and include an allowable number of segments from a baseline region containing motor unit action potentials, an allowable value for the EMG signal to baseline noise ratio, an allowable maximum value for a signal data output, values of coefficients of variables used in mathematical functions that arithmetically combine a plurality of individual parameter values into single respective parameter values, values of coefficients of variables used in a mathematical function that calculates an allowable baseline noise value based on the EMG signal to baseline noise ratio, and values of coefficients of variables used in a mathematical function that calculates an allowable value for spectral components of the line interference based on a calculated value of the EMG signal to baseline noise ratio and a calculated value of the summated motor unit action potential components power spectra.

19. Computer software according to claim **17**, wherein a compliance state of a recorded signal quality result output is provided as an accessible digital control output available for integration with other hardware and software processes.

20. Computer software according to claim **17**, further comprising:

executable code that provides a visual graphic display presentation of results output that are expanded by user activated control to include presentation of calculated parameter values of the baseline noise, line interference, and signal to baseline noise ratio, using a combination of digital and analog indicators, each marked with a value of the pre-defined performance metric for respective output parameters thereof, wherein the visual graphic display presentation includes presentation of additional descriptive text blocks associated with each respective calculated parameter value output.

1/15

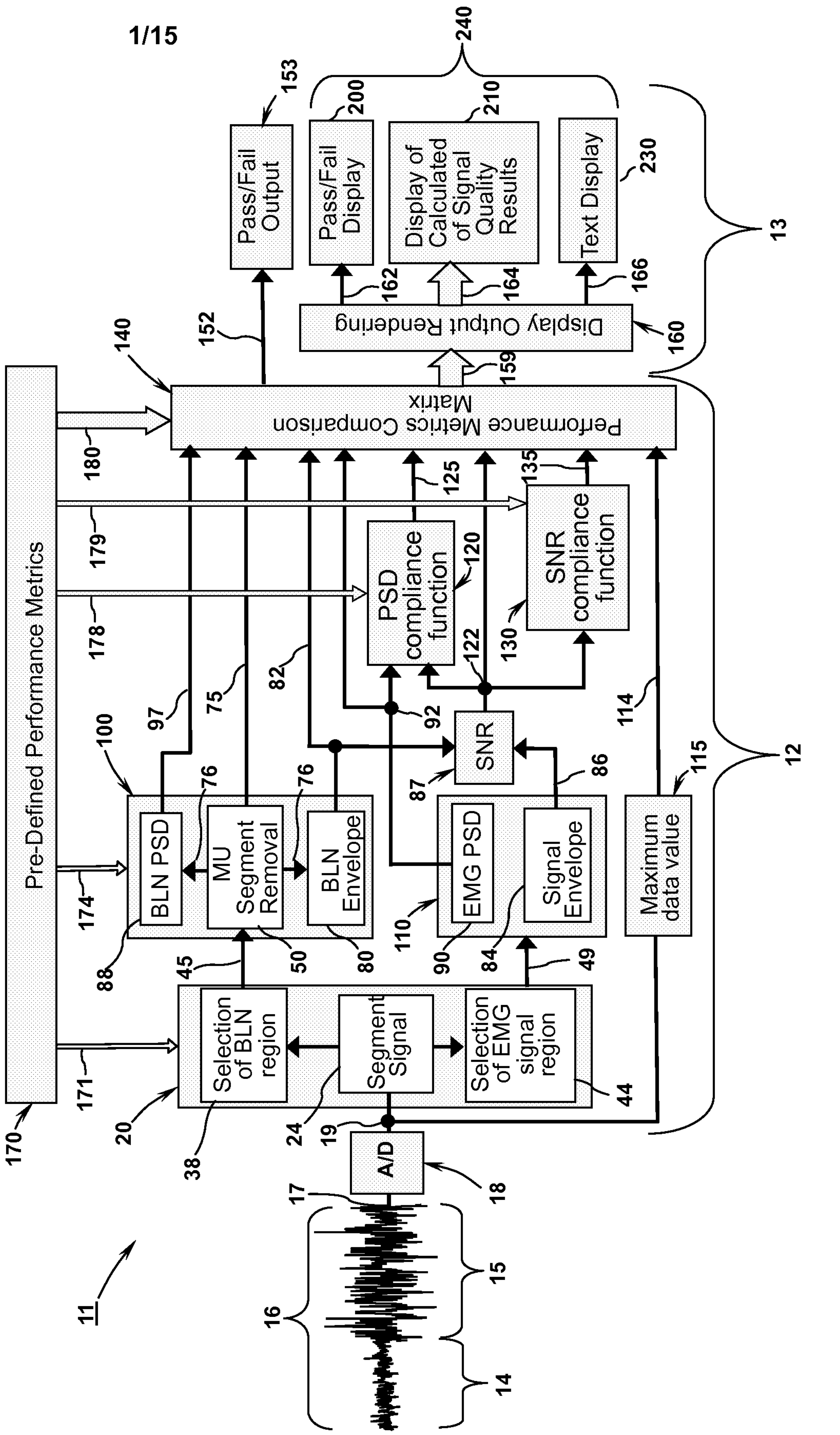

Pre-Defined Performance Metrics
Selection of BLN region
Segment Signal
Selection of EMG signal region
A/D
BLN PSD
MU Segment Removal
BLN Envelope
EMG PSD
Signal Envelope
Maximum data value
SNR
PSD compliance function
SNR compliance function
Performance Metrics Comparison Matrix
Display Output Rendering
Pass/Fail Output
Pass/Fail Display
Display of Calculated of Signal Quality Results
Text Display
11
12
13
14
15
16
17
18
19
20
24
38
44
45
49
50
75
76
80
82
84
86
87
88
90
92
97
100
110
114
115
120
122
125
130
135
140
152
153
159
160
162
164
166
170
171
174
178
179
180
200
210
230
240

FIG. 1

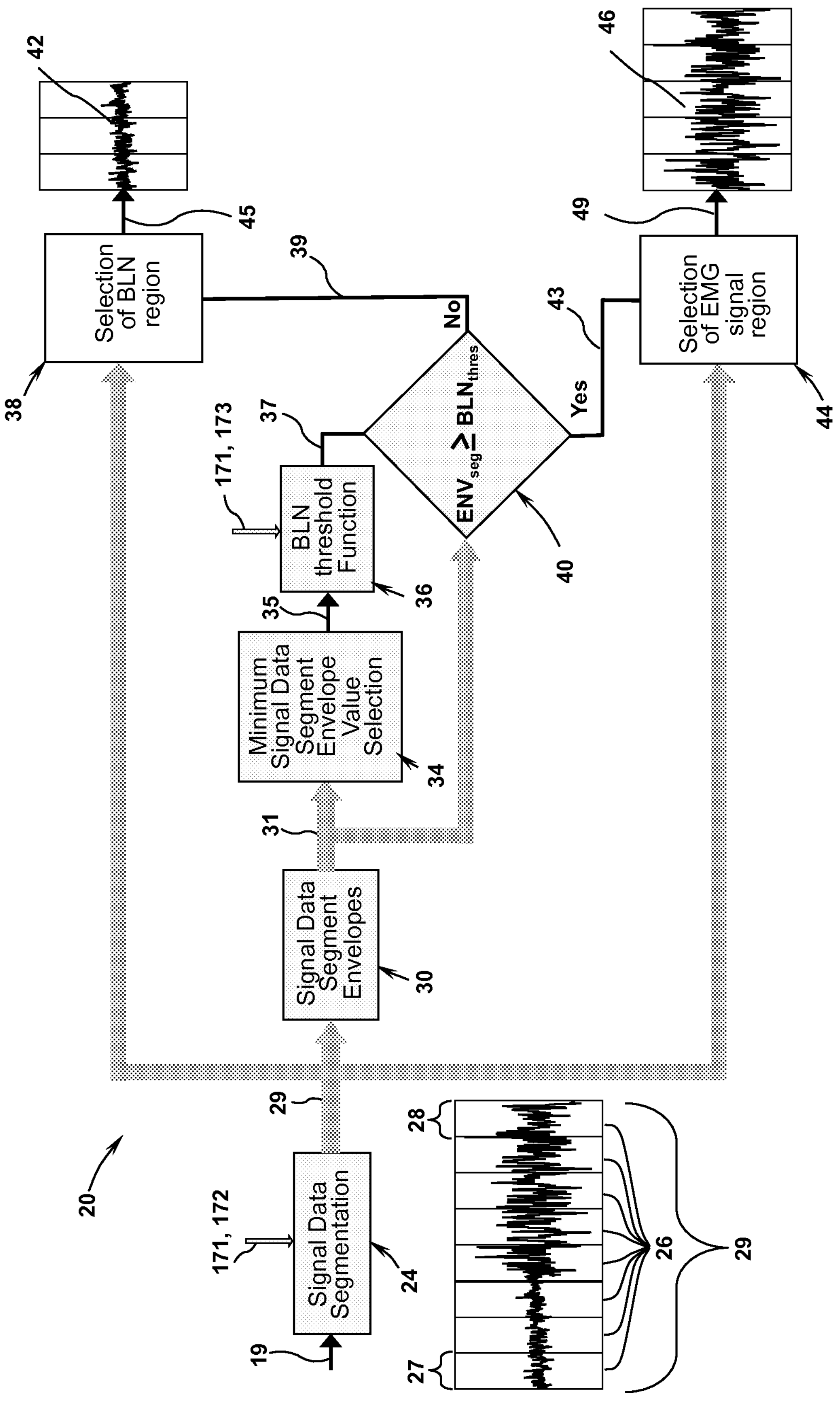

20
19
Signal Data Segmentation
24
171, 172
29
27
28
26
29
Signal Data Segment Envelopes
30
31
Minimum Signal Data Segment Envelope Value Selection
34
35
BLN threshold Function
36
171, 173
37
$ENV_{seg} \geq BLN_{thres}$
40
No
Yes
39
43
Selection of BLN region
38
45
42
Selection of EMG signal region
44
49
46

FIG. 2

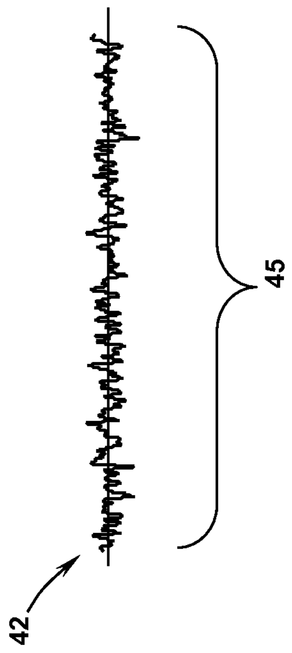


FIG. 3A

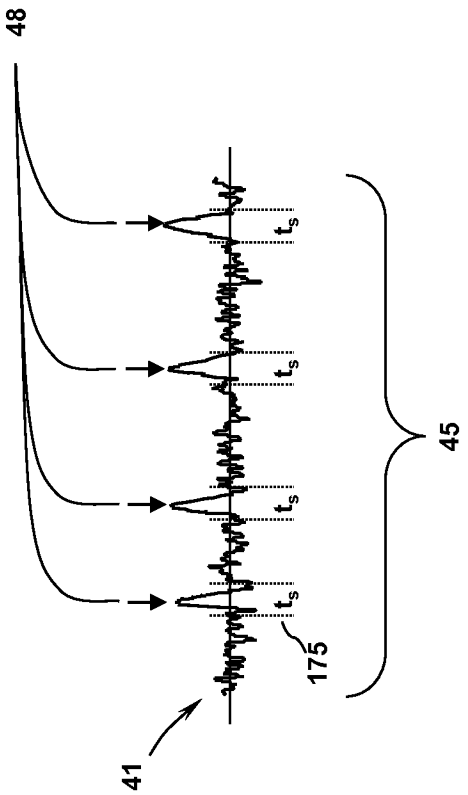
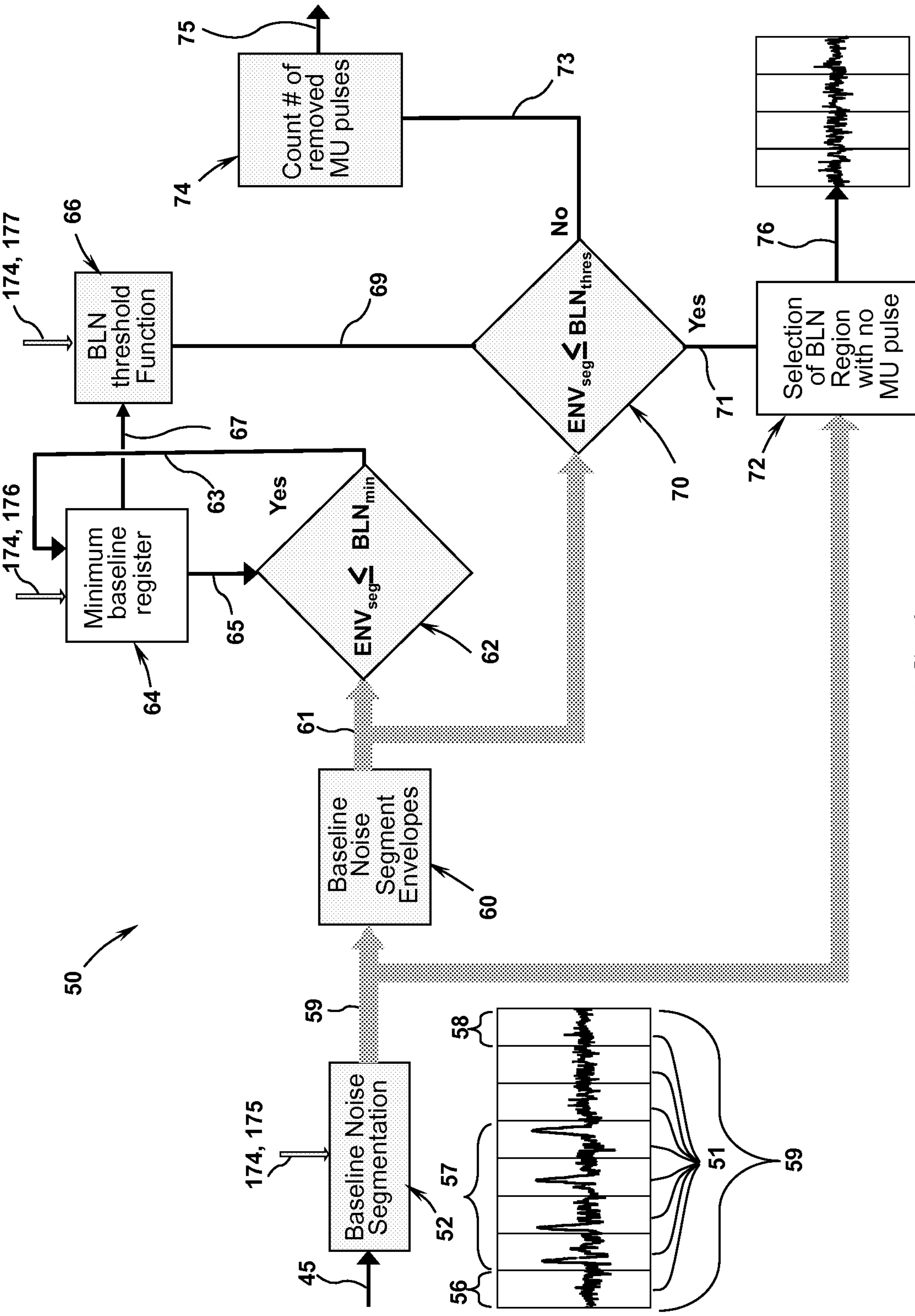


FIG. 3B



50
45
Baseline Noise Segmentation
174, 175
52
59
Baseline Noise Segment Envelopes
60
61
Minimum baseline register
174, 176
64
65
$ENV_{seg} \leq BLN_{min}$
62
Yes
63
67
BLN threshold Function
174, 177
66
69
$ENV_{seg} \leq BLN_{thres}$
70
No
Yes
71
Count # of removed MU pulses
74
73
75
Selection of BLN Region with no MU pulse
72
76
56
57
58
51
59

FIG. 4

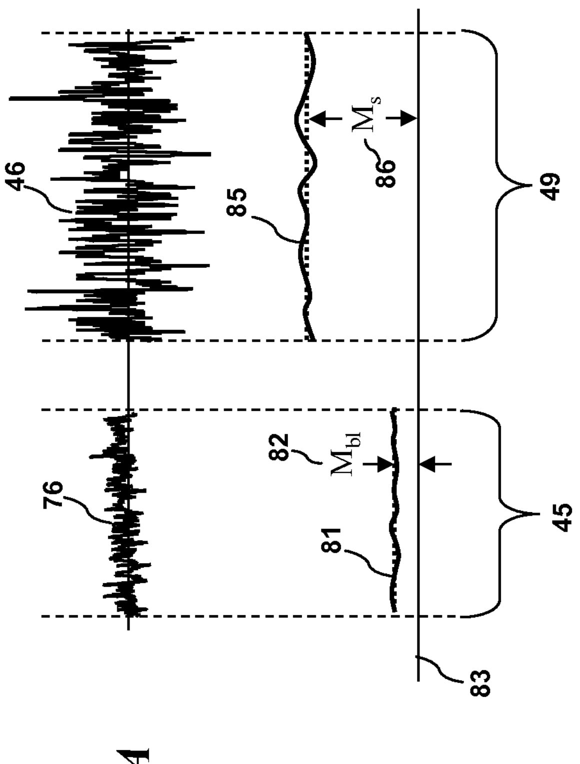


FIG. 5A

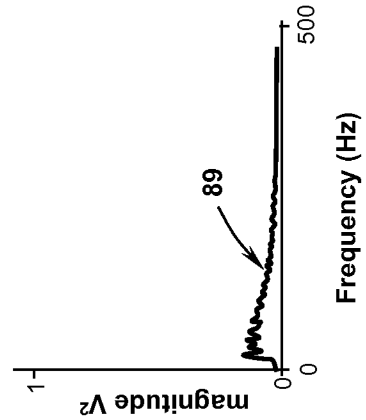


FIG. 5B

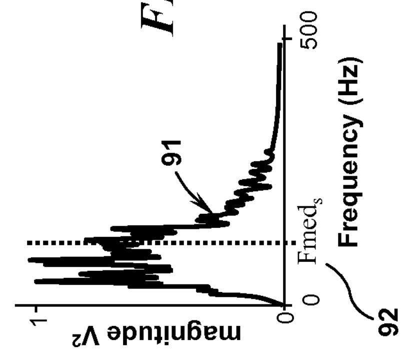


FIG. 5C

FIG. 6A

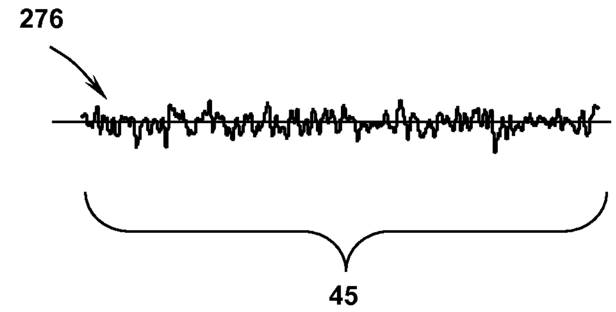


FIG. 6B

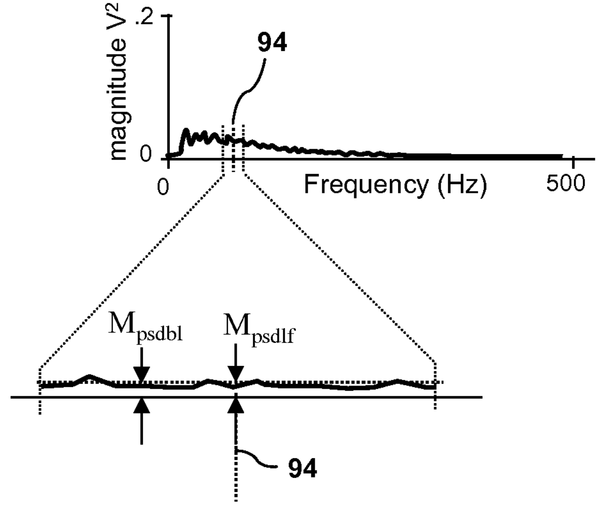


FIG. 7A

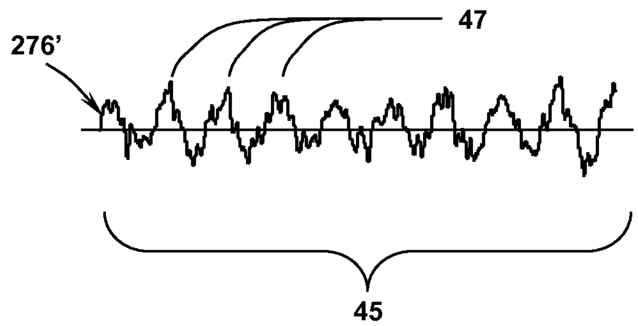


FIG. 7B

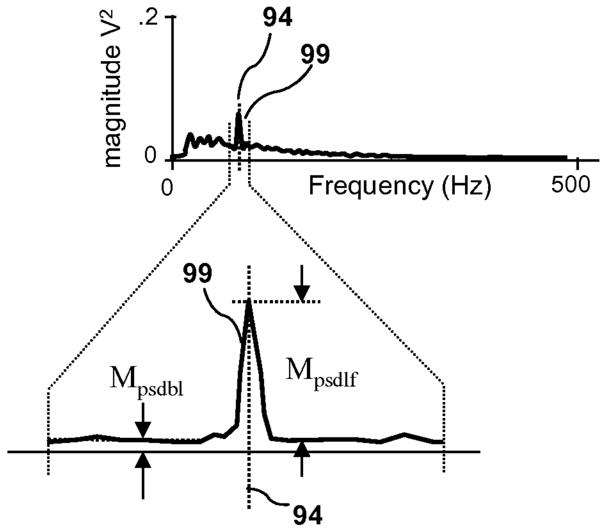
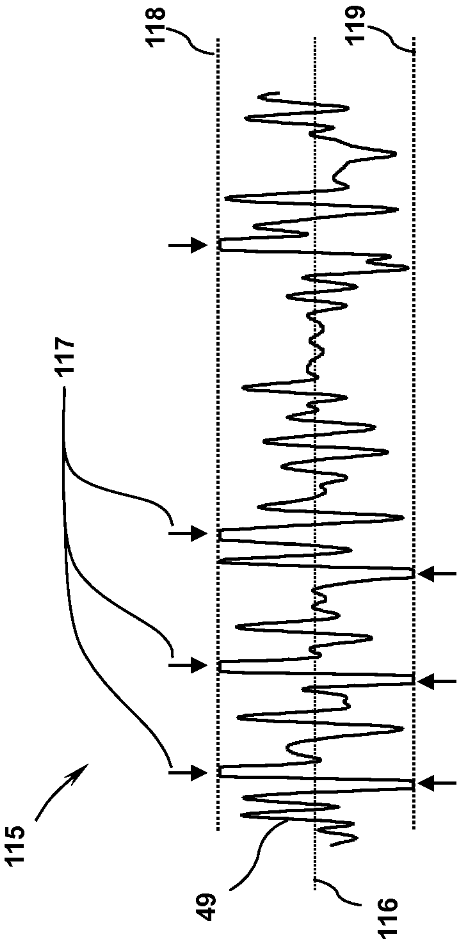


FIG. 8



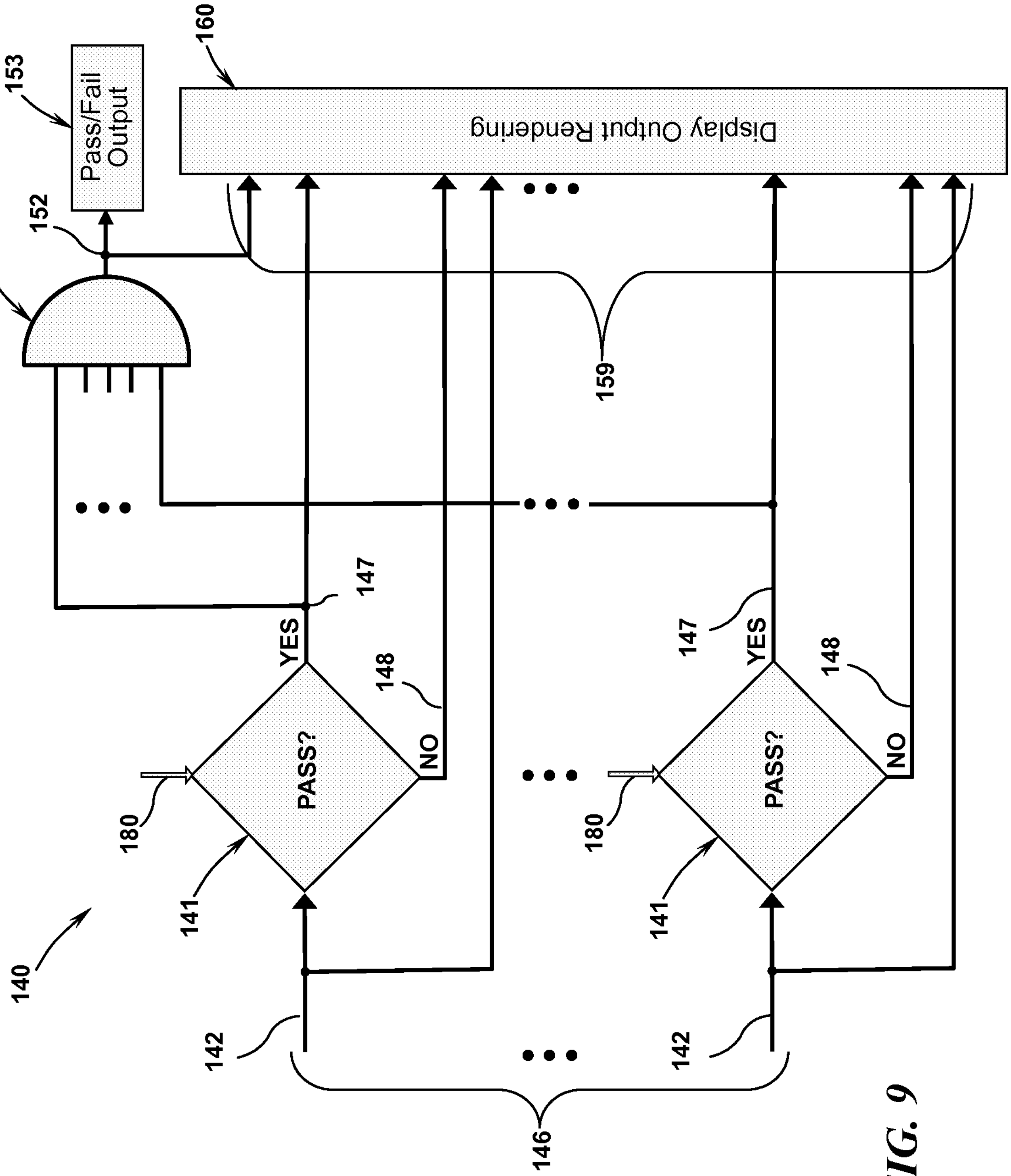

140
141
142
146
147
148
151
152
153
159
160
180
PASS?
YES
NO
Pass/Fail Output
Display Output Rendering

FIG. 9

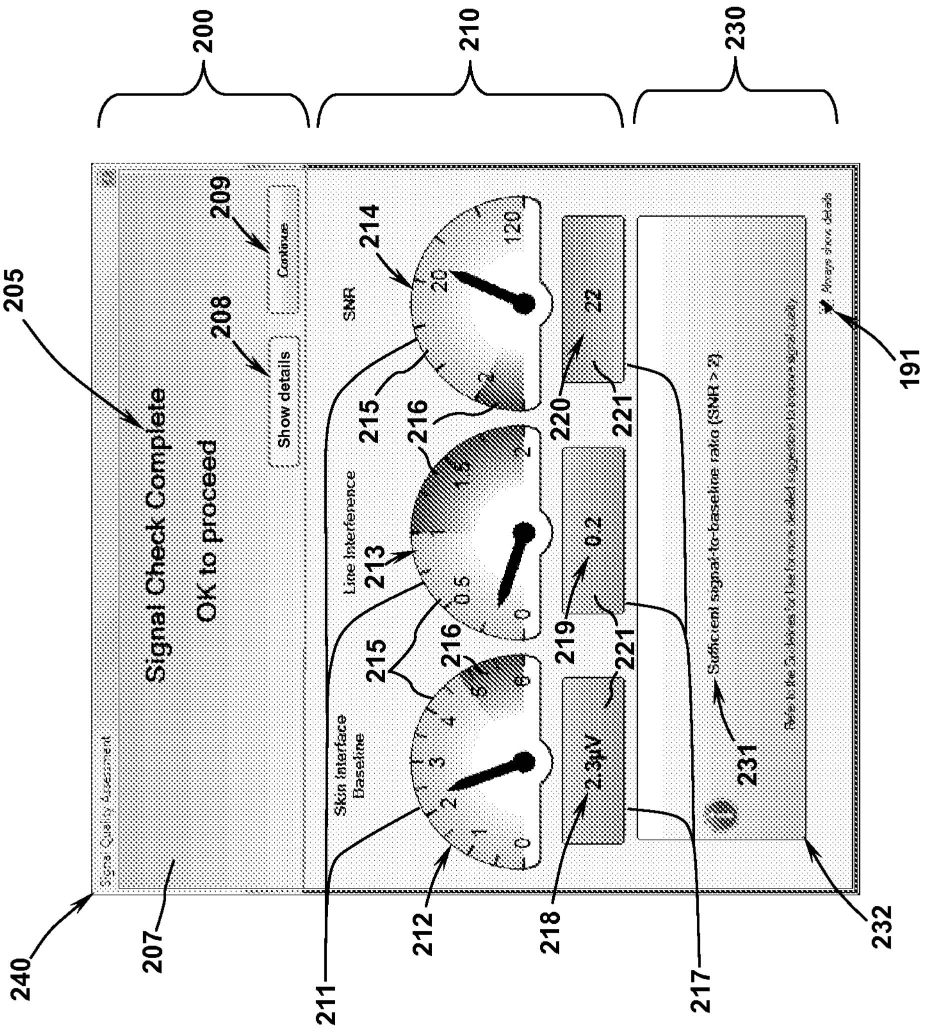

200
210
230
205
208
209
214
Signal Check Complete
OK to proceed
Show details
Continue
SNR
Line Interference
Skin Interface
Baseline
22
0.2
2.3µV
Sufficient signal-to-baseline ratio (SNR > 3)
Always show details
240
207
211
212
213
215
216
217
218
219
220
221
231
232
191

FIG. 10

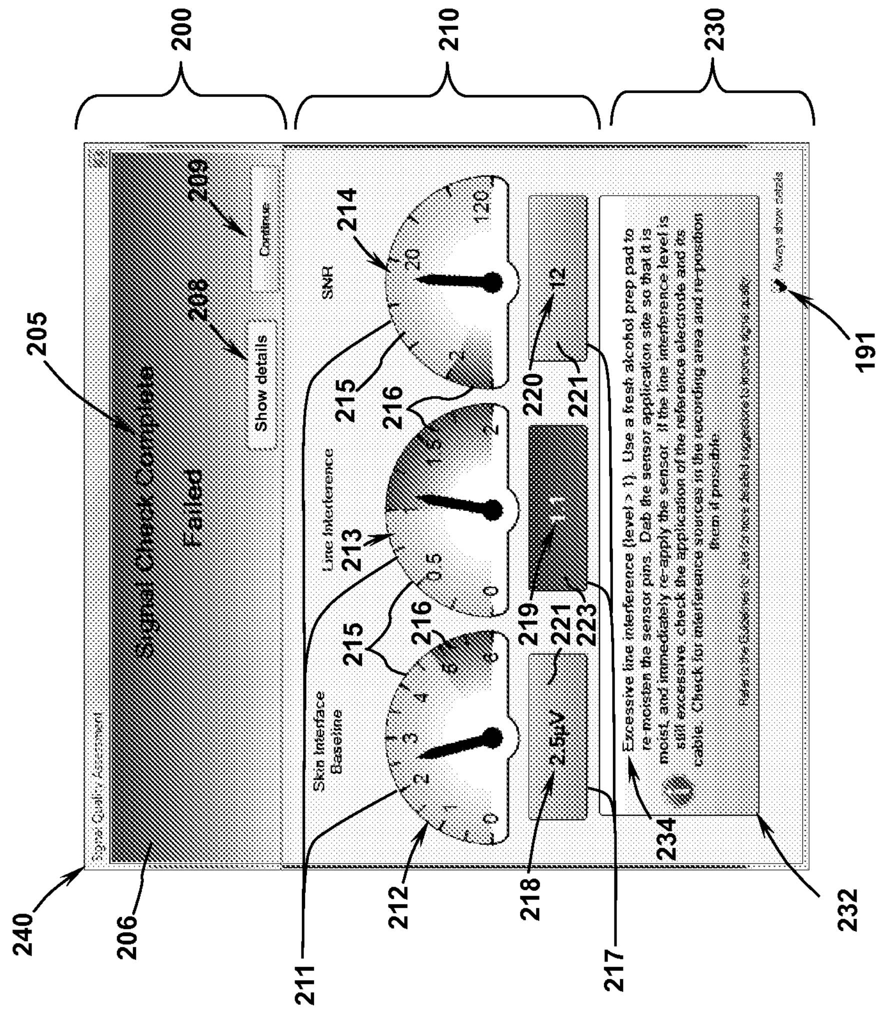
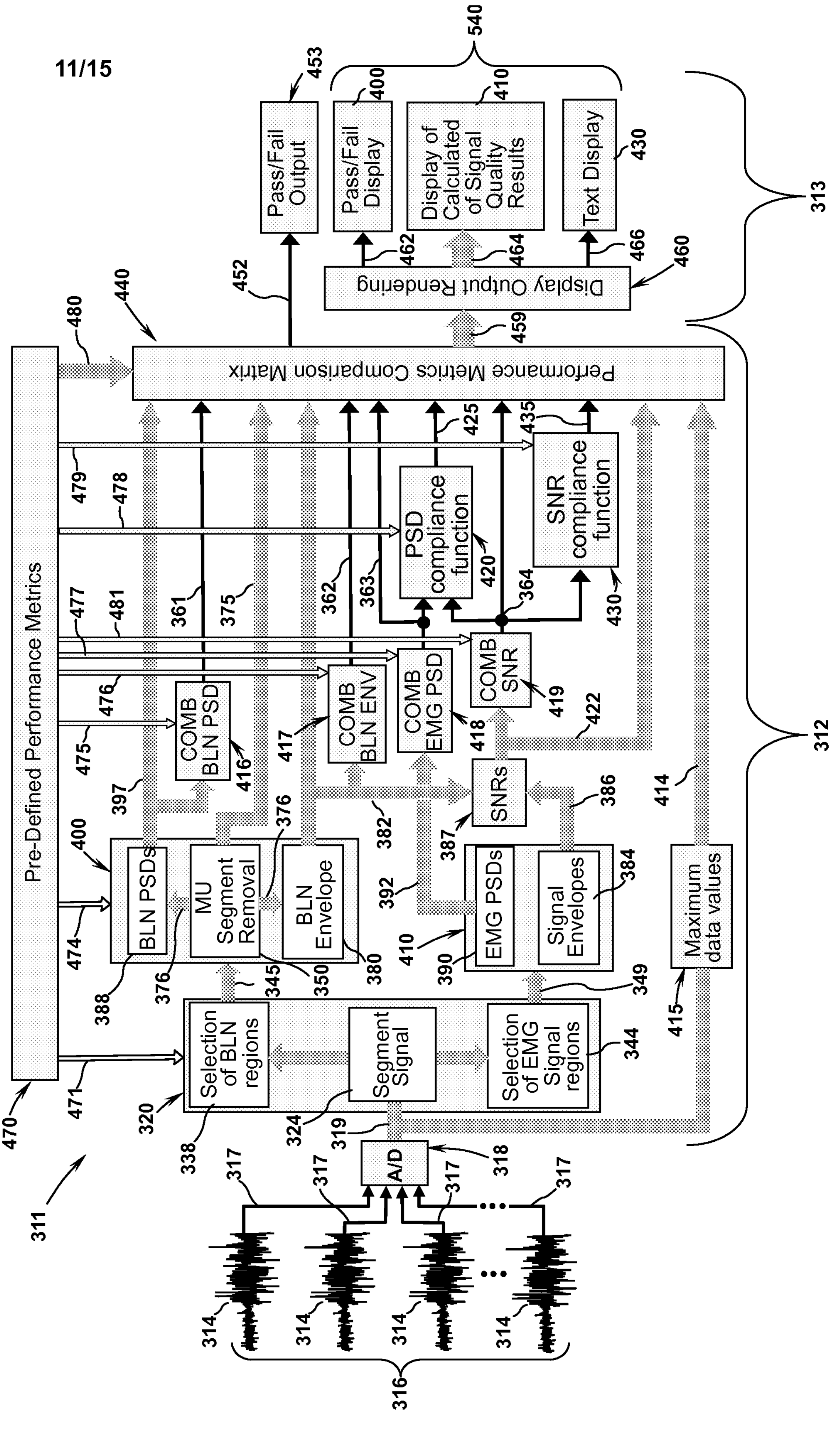

200
210
230
205
209
208
214
Signal Check Complete
Failed
Show details
Continue
SNR
Line Interference
Skin Interface
Baseline
2.5µV
1.1
12
215
216
220
221
213
219
223
212
218
211
217
234
232
240
206
191
Excessive line interference (level > 1). Use a fresh alcohol prep pad to re-moisten the sensor pins. Dab the sensor application site so that it is moist, and immediately re-apply the sensor. If the line interference level is still excessive, check the application of the reference electrode and its cable. Check for interference sources in the recording area and re-position them if possible.

FIG. 11


Pre-Defined Performance Metrics
Performance Metrics Comparison Matrix
Pass/Fail Output
Pass/Fail Display
Display of Calculated of Signal Quality Results
Text Display
Display Output Rendering
Selection of BLN regions
Segment Signal
Selection of EMG Signal regions
A/D
BLN PSDs
MU Segment Removal
BLN Envelope
EMG PSDs
Signal Envelopes
Maximum data values
SNRs
COMB BLN PSD
COMB BLN ENV
COMB EMG PSD
COMB SNR
PSD compliance function
SNR compliance function
311
312
313
314
316
317
318
319
320
324
338
344
345
349
350
361
362
363
364
375
376
380
382
384
386
387
388
390
392
397
400
410
414
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430
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464
466
470
471
474
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476
477
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480
481
540

FIG. 12

12/15

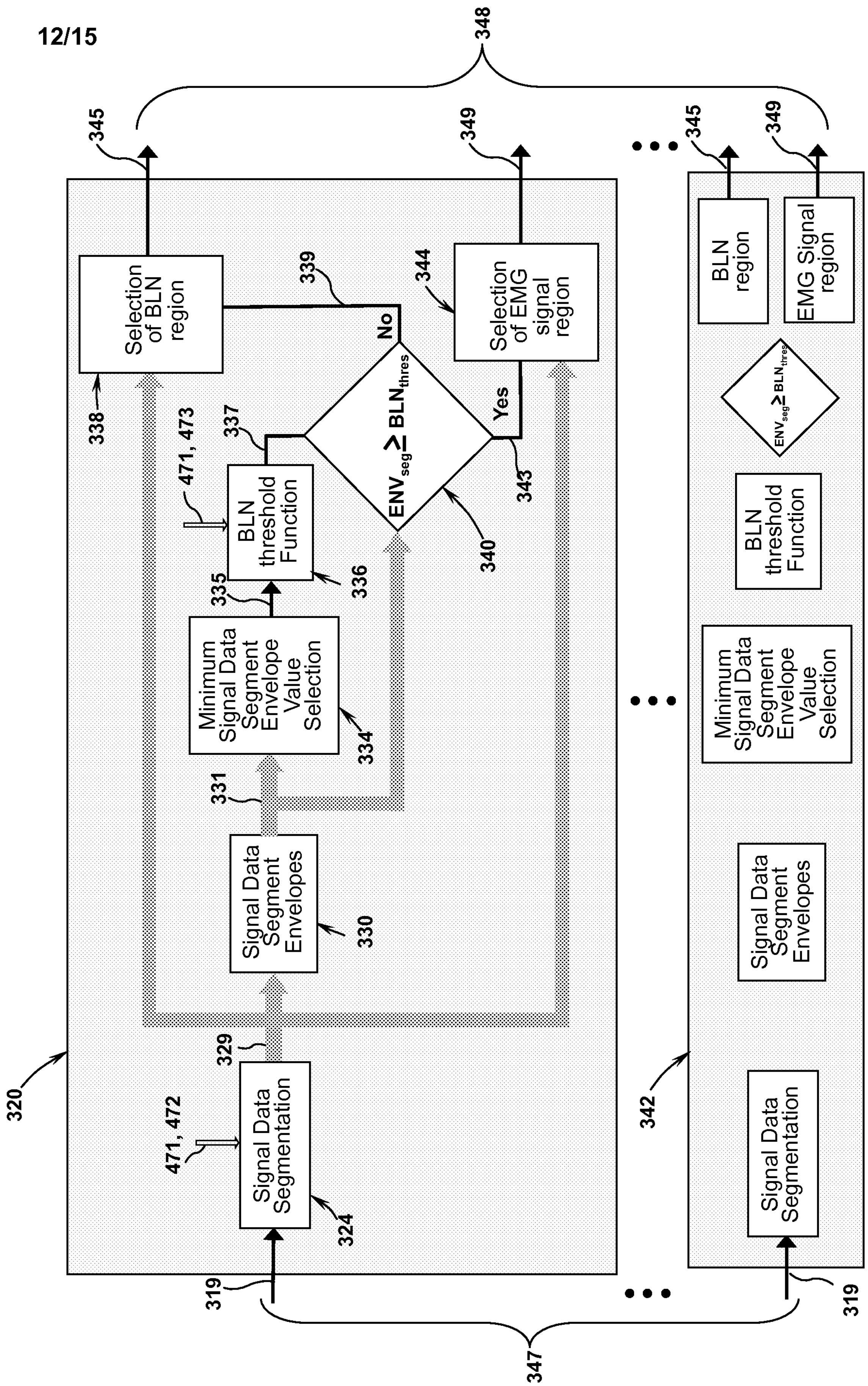

348
345
349
345
349
Selection of BLN region
339
No
344
Selection of EMG signal region
BLN region
EMG Signal region
338
471, 473
337
$ENV_{seg} \geq BLN_{thres}$
Yes
BLN threshold Function
343
340
336
335
Minimum Signal Data Segment Envelope Value Selection
334
331
Signal Data Segment Envelopes
330
329
320
342
Signal Data Segmentation
471, 472
324
319
319
347

FIG. 13

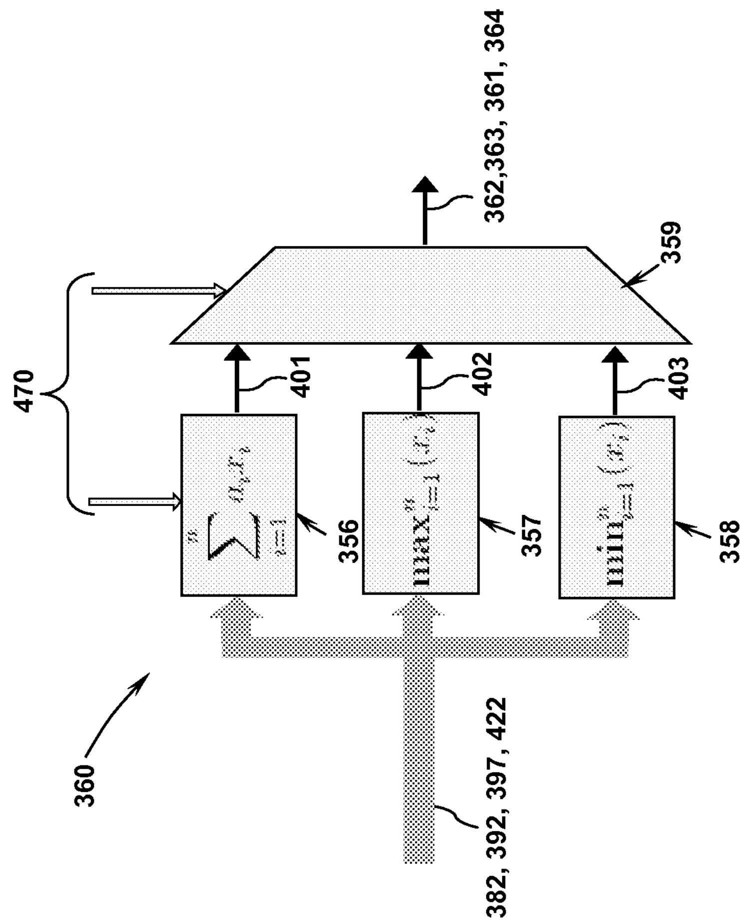

362,363, 361, 364
359
470
401
402
403
356
357
358
360
382, 392, 397, 422

FIG. 14

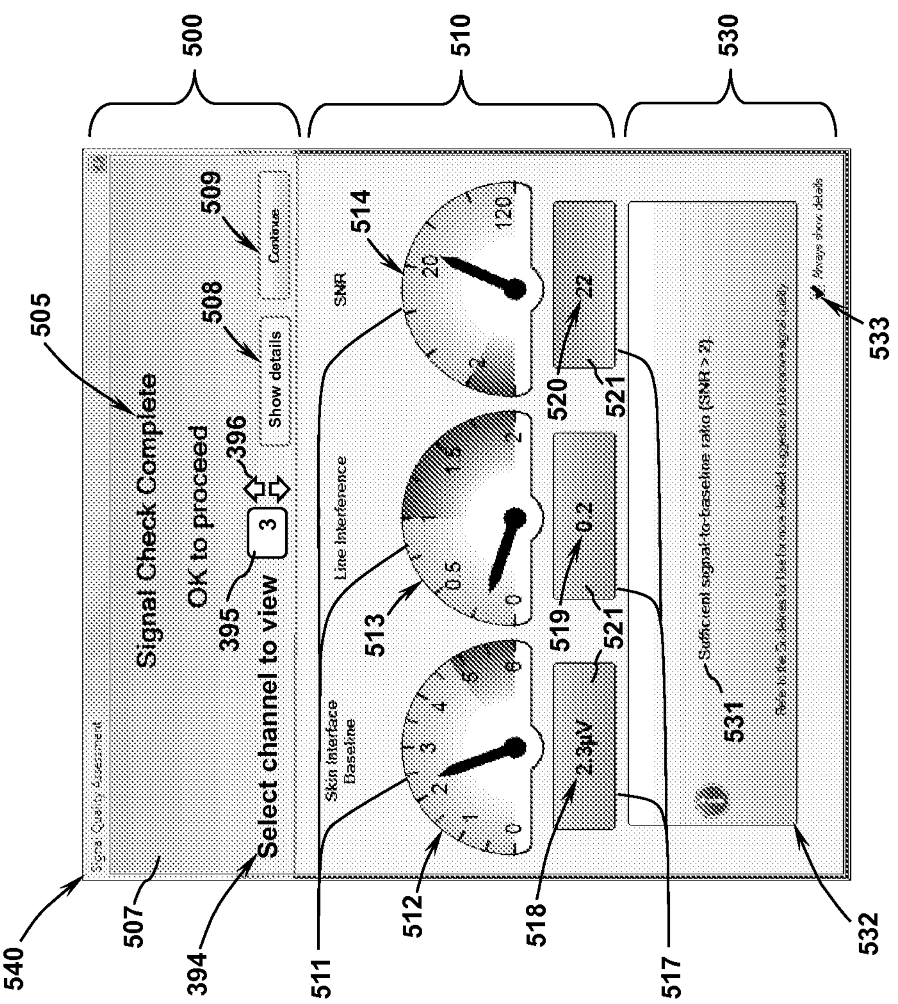
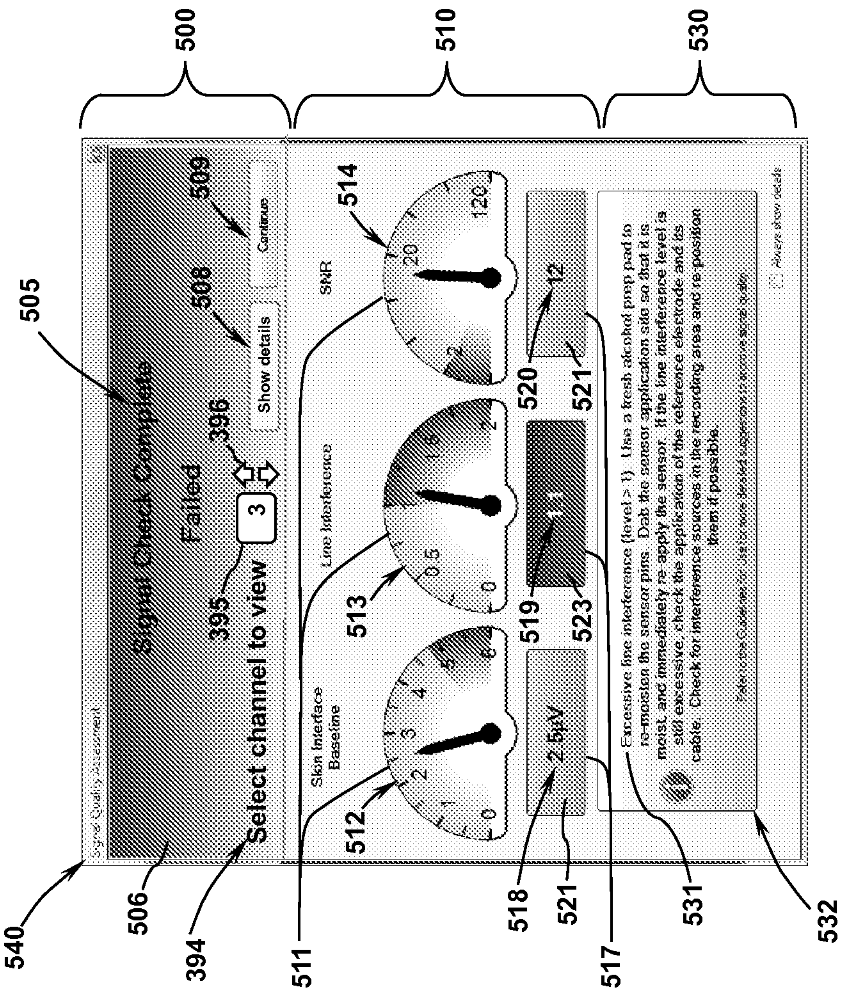

500
510
530
505
Signal Check Complete
OK to proceed
Select channel to view
3
Show details
Continue
Skin Interface Baseline
Line Interference
SNR
2.3μV
0.2
22
Sufficient signal-to-baseline ratio (SNR > 2)
540
507
394
395
396
508
509
511
512
513
514
517
518
519
520
521
531
532
533

FIG. 15



500
510
530
505
509
508
396
395
394
506
540
511
512
513
514
517
518
519
520
521
523
531
532
Signal Check Complete
Failed
Select channel to view
3
Show details
Continue
Skin Interface
Baseline
Line Interference
SNR
2.5µV
12

FIG. 16

14/012253 08.04.2014

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US14/12253

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61B 5/0488; G01R 29/26; G06F 17/18 (2014.01)
USPC - 600/546; 702/69, 179
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): A61B 5/0488; G01R 29/26; G06F 17/18 (2014.01)
USPC: 600/546; 702/69, 179

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); ProQuest; Google/Google Scholar; IP.com; Search terms used: EMG, electromyograph*, electro-myograph*, electro, myograph*, sensor*, sens*4, detect*3, measur*3, signal*, transmi*, result*, noise*, baseline*, base-line*, background*, interfer*, imped*4, motor, unit, action, potential*, unit*, perform*

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	DELSYS INC. dEMG User's Guide. May 2012; sections 1-3, 4.3.6, 4.4.8-11, 4.5.3, 4.6.6, 4.7, 4.8, 4.9.4, 4.10.1-7, 6, 6.4 <URL: https://www.delsys.com/decomp/ew4_doc%20(MAN-011-1-6).pdf>	1-3, 5, 7, 12-17, 19-20 -------- 4, 6, 8-11, 18
Y	US 2009/0201172 A1 (EDELL, DJ) August 13, 2009; paragraphs [0056], [0070]	4, 10-11, 18
Y	KONRAD, P. The ABC of EMG. Version 1.4 March 2006; page 23, paragraph 2; page 24, paragraphs 2-3; figure 32; page 27, paragraph 2; figure 37 <URL: http://www.noraxon.com/docs/education/abc-of-emg.pdf>	6, 8, 9
Y	US 5513651 A (CUSIMANO, MR et al.) May 7, 1996; claim 3	6
A	DE LUCA, G. Fundamental concepts in EMG signal Acquisition. March 2003; entire document <URL: https://www.delsys.com/Attachments_pdf/WP_Sampling1-4.pdf>	1-20
A	HOGAN, N et al. Myoelectric signal processing: optimal estimation applied to electromyography--Part I: Derivation of the optimal myoprocessor. IEEE Transactions on Biomedical Engineering. July 1980, Volume BME-27, Number 7; pages 382-395; entire document	1-20
A	DELSYS INC. How do I obtain motor unit data?. Undated (retrieved on 03 March 2014); entire document <URL: https://www.delsys.com/decomp/How%20do%20I%20obtain%20motor%20unit%20data.pdf>	1-20

☒ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 March 2014 (18.03.2014)	08 APR 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US14/12253

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	De Luca, CJ et al. Filtering the surface EMG signal: Movement artifact and baseline noise contamination. Journal of Biomechanics, May 28, 2010, Volume 43; pages 1573-1579; entire document	1-20
A	US 2006/0079801 A1 (DeLuca, CJ et al.) April 13, 2006; entire document	1-20
A	US 6720984 B1 (JORGENSEN, CC et al.) April 13, 2004; entire document	1-20
A	De Luca, CJ et al. Decomposition of surface EMG signals. Journal of Neurophisiology September 1, 2006, Volume 96; pages 1646-1657; entire document	1-20