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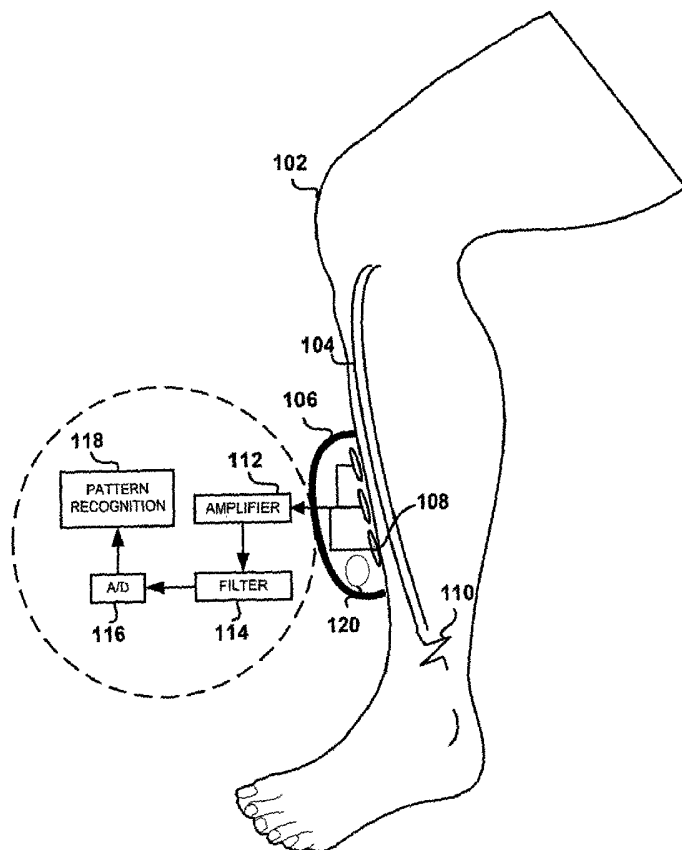
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(54) Title: METHOD AND APPARATUS FOR MEASURING NERVE SIGNALS IN NERVE FIBERS



(57) Abstract: A method and apparatus for measuring in the non-stimulated activity of a plurality of sensory nerve fibers in a predetermined nerve conduction velocity range by at least two sensors in proximity to the nerve fiber, the sensors are spaced apart such that the measurements can be correlated. The correlation between the two measured signals is correlated in a time difference reflecting a predetermined velocity range and then summing all the correlation value points measured and calculated.

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METHOD AND APPARATUS FOR MEASURING NERVE SIGNALS IN NERVE FIBERS

BACKGROUND OF THE INVENTION

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FIELD OF THE INVENTION

The present invention generally relates to a method and apparatus for detecting and quantifying electrical activity in nerves. More specifically, the present invention relates to the detection and quantification of electrical signals
10 emanating from sensory nerve fibers by the use of sensors and computer generated program.

DISCUSSION OF THE RELATED ART

Sensory information in the human body is transferred to the central
15 nervous system by a set of nerves coupled to each other in an intricate fashion. The nerves generally comprise a soma or body and an axon commonly referred to as nerve fiber, used here interchangeably. The information going through a nerve fiber is transferred by an electrical potential propagating along the nerve fiber pathway, creating an action potential. Different nerves comprise different fibers
20 with different physiological and electrical properties. The properties of each fiber determine the conduction parameters of said sensory information such as velocity, action potential shape and duration, after potential duration, decay carried by said fibers. Different sensory modalities, such as pain, pressure, touch, vibration and the like are transferred to the central nervous system via different nerves having
25 different fibers with different properties. Touch sensation is generally transferred via A α β fibers. These fibers are generally wide in their diameter and have a myelin insulating cover allowing them to transfer information at a relatively higher velocity. A significant part of the pain sensation however, is conveyed to the central nervous system via C type axons. These fibers are of generally small
30 diameter and lack the myelin cover, thus conveying information at a much slower

rate then other types of axons. In addition, action potentials conveyed in C type fibers are of a different shape and longer duration when compared to action potentials of different axons. The in vivo detection and measurement of sensory neuronal signals in general and that of the pain modality has been a challenge for
5 a long time. Pain neuronal signals measurement is limited at present to the activity of single neurons with a needle electrode. For such a measurement to be accomplished, nerve axon stimulation is required. After a needle is inserted to a close proximity of an axon, a nociceptive or an electrical stimulation is given and a recoding electrode is used for measurement of said axon activity. Another
10 method to measure related method is known as is EMG recording in which the compound myoelectric signal of one or more motor units' action potential trains is measured. This method requires that the action potentials created by the multiple muscle fibers responding to these trains be amplified. A third known method is nerve conduction velocity measurement, according to which the velocity in which
15 a compound evoked response of a nerve to an electrical stimulus is measured. This biopotential is stronger in about two orders of magnitude when it is measured in the efferent motor direction and is considerably weaker when it measures only the neuronal response in the sensory afferent direction. All three methods require signal amplification, the first by using needles inserted in very
20 close proximity to a single nerve fiber, the second by the amplification created by the response of the many muscle fibers to one motor neuron and the third by using the synchronized reaction of multiple fibers to an electric stimulus. One disadvantage of these methods is that they have not been able to measure the overall non stimulated sensory activity such as pain. The first method is able to
25 measure only single action potentials, the second measures the muscle rather than neuronal activity and the third requires an external stimulus. Another disadvantage of the prior art process is that it fails to measure signals traveling at low velocities since such signals are less correlated. Another disadvantage of the three methods noted above is that none of the methods is able to measure the
30 separate non-stimulated activity in each specific sensory modality of a nerve

bundle, the first is able to measure only single neurons and does not measure their velocity, the second does not measure sensory activity and the third measures only stimulated activity.

Pain is one of the most common presenting symptoms in medicine.

5 Pain, is in most cases, transferred through the low conduction velocity nerves including A δ and C nerve fibers. Pain, however, is extremely hard to assess objectively. Clinically, pain is generally assessed via the use of a visual scale analogue (VAS) meter as well as by special questioners. Both systems are highly subjective and limit the ability of the clinician to assess the pain level of the
10 patient. This often leads to either excessive or under treatment of the patient. More objective methods of measuring pain include the measurement of the body temperature as well as conductance. These measurements however are non-specific and cumbersome to perform, therefore rarely used clinically. There is therefore an urgent need for a simple to use, as well as, an accurate method and
15 device for the measurement of sensory information particularly that of pain traveling to the central nervous system. Such a device should preferably be non-invasive and harmless to the patient, easy to use and having meaningful clinical information. This device should also be able to perform such measurements when applied to fiber bundles and isolated fibers alike.

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SUMMARY OF THE PRESENT INVENTION

It is an object of the present invention to provide a method and apparatus for measuring in the non-stimulated activity of a plurality of sensory nerve fibers in a predetermined nerve conduction velocity range.

25 It is also an object of the present invention to provide a method and apparatus for measuring the neuronal sensory activity in each specific modality such as touch, temperature, pain, proprioception smell and the like.

It is also an object of the present invention to provide a method and apparatus for measuring the neuronal sensory activity in each specific modality
30 for implantable units that can use this information for their operation.

It is also an object of the present invention to provide a method and apparatus for measuring the nerve signal on at least two sensors in proximity to the nerve fiber, the sensors are spaced apart such that the measurements can be correlated.

5 It is further an object of the present invention to provide a method and apparatus for calculating the correlation between the two measured signals in a time difference reflecting a predetermined velocity range and then summing all the correlation value points measured and calculated.

10 It is also an object of the present invention to provide electrodes and a processing unit in order to measure the action potentials progressing through a nerve fiber along its pathway. The present invention enables to measure the level of nerve activity especially at a slow conduction velocity, using a non-invasive electrodes signals (non stimulated).

One aspect of the present invention regards an apparatus for measuring
15 the non-stimulated activity of a plurality of sensory nerve fibers, the apparatus comprising: at least two sensors in proximity to the nerve fibers for measuring signals passing through the sensory nerve fibers, the sensors are spaced apart such that the measurements can be correlated; and a pattern recognition device for correlating the measurements in a time difference reflecting a predetermined
20 velocity range. The apparatus further comprises an amplifier for amplifying the signals measured by the at least two sensors; and a filter for filtering the signal measured by the at least two sensors. The pattern recognition device counts the number of action potential spikes passing through the nerve fibers. The pattern recognition device further sums all the correlation value points measured and
25 correlated. The correlation is performed through cross correlating the measurements and calculating the conduction velocity distribution. The apparatus can further comprise an output device for providing an output signal to a user, said output signal showing the sensory nerve activity signal level. According to one embodiment the distance between the at least two sensors is less than about 3
30 centimeters. The filter is a high or low band pass or notch filter. The sensors are

active or passive electrodes. The apparatus can further comprise a communication device for transmitting the measurements or processed measurements to a remote device. The apparatus can be an implantable device or a device used in inside the body and remotely to the skin. The apparatus can further comprise a wireless device for sending the activity level to a remote device for monitoring patients' nociception level.

A second aspect of the present invention regards a method for measuring the non-stimulated activity of a plurality of sensory nerve fibers, the method comprising the steps of receiving a nerve potential activity signal through at least two sensors; amplifying the received signal; filtering the amplified signal for detecting the specific action potential signal from the entirety of the signal received and amplified; determining and storing the signal associated with sensory nerve signals from the signals filtered by cross correlating between two predetermined signal; and calculating the activity of the signal associated with sensory nerve signals through the use of an operator for determining that a sensory nerve action potential is present. The step of determining comprises recognizing the pattern of an A or C nerve action potential. The operator can be an integral of the conduction velocity distribution calculation. Alternatively, the operator can be an integral of the conduction velocity distribution calculation between two velocities of two signals received, corresponding a sensory nerve velocity range, or a comparison of the conduction velocity distribution to a predetermined histogram. The method can further comprise the step of determining whether the result of the operator indicates a valid signal or the step of presenting an output to a user. The method can further comprise the step of processing the next active signal or the step of incorporating predetermined parameters relating to a user or a patient with the output signal such that in accordance with such parameters the output signal may vary. The cross correlating between two predetermined signal comprises cross correlating between a signal measured by the at least two sensors and a template predetermined signal. Alternatively, the cross correlating between two

predetermined signal comprises cross correlating between signals measured by the at least two sensors.

Where the cross correlation is between two predetermined signal comprises the steps of initializing the action potential, time of measurement and first and second width variables; updating the first and second width variables; 5 acquiring an action potential; cross correlating the action potential with a template having a first width; cross correlating the action potential with a template having a second width; determining whether the second width is not smaller than a predetermined minimum width value and if no determining if a maximum point 10 of the cross correlation with the second width is grater than a maximum point of the cross correlation with the first width. In this embodiment pattern generation is determined according to a calculation between at least two signals. The following steps are performed: receiving the longitude distance between the at least two sensors such that the signal received in the two sensors to be correlated; 15 calculating the expected time difference for a signal to arrive in a predetermined velocity range wherein the maximal time difference is equal to the time difference divided by the maximum predetermined speed range for the signal while the minimal time difference is equal to the time difference divided by the minimum predetermined speed range for the signal; receiving measurements from the at 20 least two sensors; calculating the cross correlation between the measurements of the at least two sensors; calculating the integral of the cross correlation results between the minimal and maximal time differences. The method will further comprise the step of summing the cross correlation values an area proportional to the activity of a nerve signal in the signal minimum and maximum speed range, 25 and the step of storing each measurement and each result. The calculation of the cross correlation is performed for at least the minimal and maximal time difference.

The method can further comprise the step of decreasing the first and second width if the maximum point of the cross correlation with the second width 30 is grater than the maximum point of the cross correlation with the first width

further or the step of multiplication of the first and second width if the maximum point of the cross correlation with the second width is not greater than the maximum point of the cross correlation with the first width further.

5 The method can further comprise the step of obtaining the next action potential or the step of determining that the cross correlation with the template having the first width is the correct calculation and further calculating the maximum point of the cross correlation.

BRIEF DESCRIPTION OF THE DRAWINGS

10 The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

Fig. 1 is a side view of a general illustration of an apparatus for measuring the electrical activity of nerves, from a body surface, in accordance with the present invention.

Fig. 2 is a flow chart depicting steps used for measuring the non-stimulated activity of a plurality of sensory nerve fibers, in accordance with the present invention.

20 Figs. 3A, 3B are flow charts depicting steps performed by the pattern recognition device measuring the non-stimulated activity of a plurality of sensory nerve fibers, in accordance with the present invention.

Fig. 4A, presents a schematic illustration of a multiple electrodes array, in accordance with the present invention.

25 Figs. 4B, 4C 4D are schematic illustrations of examples for improving signal to noise ratio using summation from different sensors, in accordance with the present invention.

Fig. 5A, 5B, 5C are schematic illustrations of examples for detecting a signal propagating in sensory nerve fibers, using cross correlation, in accordance with the present invention.

Fig. 6 is a schematic illustration of the top view of the apparatus for measuring the electrical activity of nerve signals, in accordance with the present invention.

5 Figs. 7A, 7B are schematic illustrations of exemplary uses of a device measuring the electrical activity of nerve signals, especially pain level, in accordance with the present invention.

Figs. 8A is an examples for use of a device measuring the electrical activity of nerve signals, for measuring pain development during time, in accordance with the present invention.

10 Fig. 8B is a graph showing the results of measurements made over a period of time.

Fig. 9 is an illustrated example for one possible use of the device for measuring the electrical activity of nerve signals, for selectivity disconnecting nerve fiber, in accordance with the present invention.

15 Fig. 10 shows illustrated examples for transferring information form the apparatus for measuring an electrical activity of nerve signals, in accordance of with the present invention.

Fig. 11 is a side view of a general illustration of an implantable apparatus measuring the electrical activity of nerves, in accordance with the
20 present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention relates to a method and apparatus for detecting and measuring electrical activity of nerve signals in nerve fibers having a slow or a predetermined conduction velocity, for example C nerve fibers in a human being or an animal. The present invention provides a method and apparatus for measuring the non-stimulated activity of a plurality of sensory nerve fibers in a predetermined nerve conduction velocity range. Also provided are a method and apparatus for measuring the nerve signal on at least two sensor in proximity to the nerve fiber, the sensors are spaced apart such that the measurements can be correlated. The correlation between the two measured signals in a time difference reflecting a predetermined velocity range and then summing all the correlation value points measured and calculated. The present invention also provides electrodes and a processing unit in order to measure the action potentials progressing through a nerve fiber along its pathway and enable to measure the level of nerve activity especially at a slow conduction velocity, using a non-invasive electrodes signals (non stimulated).

A typical velocity of a signal propagating in a low conduction velocity nerve fiber such as C fiber is about 0.4 – 2 meter per second (m/s), while the velocity of a signal propagating in a medium conduction velocity nerve fiber such as $A\delta$ is 4-36 m/s. The velocity in $A\beta$ nerve fiber is 36-72 m/s and the velocity in $A\alpha$ is 72 –120 m/s. A signals propagating through a low average conduction velocity nerve fiber accumulate a bigger relative phase to one each other, due to the relative velocity dispersion, as compared to nerve fibers with higher average conduction velocity. As a result, the sum of the signals in a low conduction velocity nerve fiber has a lower amplitude than the compound signal in a higher conduction velocity nerve fiber, due to out of phase's summation. The low amplitude turns such signals to be undetectable in current methods. The present invention enables to detect, calculate and interpret such signals, without using stimulating electrodes; by placing, relatively close two or more electrodes and measuring the traveling signals using multiple electrodes along the nerve

pathway. The use of a correlation function between the detected signal of relatively close electrodes may overcome the lower amplitude of a lower conduction velocity nerve signals and make such signals detectable.

Reference is now made to the figures in accordance with which the method and apparatus of the present invention will be described in detail. Fig. 1 is a side view of a general illustration of an apparatus for measuring the electrical activity of nerves, from a body surface, in accordance with the present invention.

The apparatus is capable of measuring low potential activities or high potential activities while progressing through a nerve fiber by detecting the signals in two points or more along the pathway of the nerve fiber. In a case of low activity, the present invention uses "spike counting" method, while in a case of high potential activity (tens of thousands or more spikes) the present invention uses correlation function method. In addition, the present invention eliminates the need of using stimulating or invasive electrodes.

Fig. 1 is a side view of a general illustration of an apparatus for measuring the electrical activity of nerves, from a body surface, in accordance with the present invention. Apparatus 106 (shown not to scale) comprises one or more electrodes or sensors 108 in order to measure the electrical activity of nerve fiber 104 from body surface 102 non-invasively. The apparatus further comprises an amplifier 112 for amplifying the measured signal, a filtering device 114 for filtering the measured signal, an analog to digital (A/D) converter 116 for converting the analog measured signals into digital format signal, a pattern recognition unit 118, a micro processor (not shown), optionally a wireless transmitter 120 for transmitting data processed by the apparatus to a remote location, and a means for signaling the output signals to the user of the apparatus (not shown) such as a display device or a speaker providing audible indication. Electrodes 108 are located within apparatus 106 such that they are sufficiently close to the skin when apparatus 106 is placed on the skin so as to detect and measure action potentials traveling along fiber 104. Electrodes 108 can be an active or passive electrodes distant less than 3 cm apart (if used for C nerve

fibers) . An active electrode is an electrode in which the first amplifier stage is on the electrode. The use of active electrodes reduces the 50/60 Hz interference pickup by the electrode and its wires, even when the electrode impedance is high (in the about 100 k Ω range). An active electrode 100 can be a flat type active electrode manufactures by BioSemi biomedical instrumentation of the Netherlands. According to one embodiment of the present invention, apparatus 106 counts the number of spikes 110 going through the nerve fibers. Alternatively, according to another embodiment of the present invention, apparatus 106 measures the action potential using a cross correlation function from which the conduction velocity distribution (CVD) is calculated. One advantage of using a conduction velocity distribution histogram is that in case of high potential activity; where spike counting is impossible, the overall number of spikes can be calculated from the CVD histogram. Another advantage of using a conduction velocity distribution histogram is that few or a decline in the number of events at a certain velocity may imply a problem at the nerves having that conduction velocity value measured.

Fig. 2 is a flow chart depicting the main steps used for measuring the non stimulated activity of a plurality of sensory nerve fibers, in accordance with the method of the present invention. In step 200, the apparatus 106 of fig. 1 is waiting to receive a nerve potential activity signal through one or more of the active sensors or electrodes. In step 210 an amplifier, preferably an operational amplifier, amplifies the signal that is received from the electrodes. A high pass or a low pass or a band pass or a notch filter or combinations thereof is used to detect the specific action potential signal from the entirety of the signal measured and amplified. In step 230, a pattern recognition device determines the relevant signal associated with sensory nerve signals from the signals filtered. For example, the pattern recognition step determines which signals are C nerve signals or A nerve signals and the like. The operation of the pattern recognition step will be further detailed and explained in accordance with Figs. 3A, 3B. In step 240 the activity recognized and determined in the pattern recognition step is

calculated through the use of an operator in order to determine that an A or C nerve action potential is indeed present. One preferred operator may be the integral of the CVD between two velocities which corresponds to the C nerve velocity range. Using such an operator results in the number of spike or "firing" of the nerve. Another such operator may be a comparison of the CVD to a predetermined histogram. Such a comparison may results in detection illnesses or phenomena that influence the conduction velocity of nerves as was mentioned before. In step 250 it is determining whether the result of operation calculated in step 240 indicates a valid signal. If yes, the output is presented to the user. If no, the next active signal is processed. The output signal to the user can be a visible indication sent to a display device such as a small LCD or an audible sound of varying height or an indication sent to a remote place such as to a computer device located remote to the apparatus. In step 270 supporting parameters relating to the user or patient or a combination thereof are incorporated with the output signal such that in accordance with such parameters the output signal may vary. Such supporting parameters are to be determined as results of experiments, research or online measurements. Such supporting parameters may be for example: previous or predetermined C-nerve activity, previous or predetermined A- δ activity, relative temperature, skin impedance, nerve conductive latency, age, gender, height, health parameter and heart rate. Persons skilled in the art will appreciate the many other parameters that can be used in association with the determination of the output signal.

Figs. 3A, 3B are flow charts depicting the steps performed by the pattern recognition device measuring the non stimulated activity of a plurality of sensory nerve fibers, in accordance with the present invention. In step 280, the action potential and time of measurement are initialized. The first action potential AP is acquired in step 282. In step 284 the cross correlation between the signals measured from the at least two or more close electrodes is calculated. The area of the cross correlation in the range which corresponds to the interested nerve fiber conduction average velocity is calculated. For example, for C-nerve fiber the

conduction average velocity may be 0.7 m/s +/- with a standard deviation of 3 m/s. The distance between the two closest electrodes may be for example 1 cm, but can be higher, and in C nerve up to about 3 centimeters.

Fig. 3B depicts in more detail the steps performed by the pattern recognition device measuring the non stimulated activity of a plurality of sensory nerve fibers. In step 300 the variable dx is calculated as the longitude distance between the at least two sensors in close proximity along a nerve fiber bundle direction. The variable dx should be such to enable the expected signal received in the two sensors to be correlated. The longitude distance between the sensors relates to the projection of the vector distance between the sensors on the vector that represent the nerve fiber. Next in the same step, calculating the expected time difference for a signal to arrive in the predetermined velocity range were the maximal time difference dt_{max} is equal to dx/v_{min} while the minimal time difference dt_{min} is equal to dx/v_{max} . This calculation can be performed anytime before the calculation of the Area in step 306. In step 302 measurements are taken from the at least two sensors or electrodes $s1$ and $s2$. In step 304 the cross correlation (X) between measurements $s1$ and $s2$ is calculated. The cross correlation (X) is calculated for dt_{min} and dt_{max} . In step 306 the calculation of the integral of the cross correlation results between dt_{min} and dt_{max} . A naive sum of the cross correlation (X) values in the predetermined ranges provide the about search area. The search area is proportional closely to the total activity of the nerve signal in the v_{min} to v_{max} speed range. The results is the cross correlation between the measuring points and is further stored for each measurement and result in step 306.

Alternatively, a cross correlation between a measured signal and a template predetermined signal, which is the excepted signal, may be conducted. In this case, the width of the predetermined signal is iteratively changed in order to compensate the natural velocity expansion of nerve signals while progressing though the nerve fiber. Such compensation is needed if ones want to detect the entire signal without missing signals with small velocity perturbations or changes.

Fig. 4A, presents a schematic illustration of a multiple electrodes array, in accordance with the present invention. Figs. 4B, 4C 4D are schematic illustrations of examples for improving signal to noise ratio using summation from different sensors, in accordance with the present invention. Electrodes 401 and 403 are located near a nerve fiber 404. The distant 402 between electrodes 401 and 402 is proportional to the typical velocity of signals in the measured nerve fiber. In accordance with the preferred embodiment of the present invention, the electrodes 401, 403 are positioned apart in a distance 402 small enough for the decay of the signal to be relatively small.

Fig. 4B presents a schematic drawing of the signal 400 as detected by electrodes 401. The detected signal has a main peak 410, which is related to the desired signal and a small peak 411 which is related to undesired signal or noise. In the same manner, Fig. 4C presents a schematic drawing of the signal 400 as detected by electrodes 403. The detected signal of electrode 403 has a main peak 420. There is a time shift 421 between the two detected main peaks from electrodes 401 and 403. By calculating time shift 421, and averaging the two signals, adding one of them the calculated time shift 421, the noise peaks 411 can be decreased. Fig. 4D presents a schematic drawing of a possible result of an averaging two signals using a time shift. The main peak 430 remains the main peak and the noise peak 431 decreased. Time shift 421 can be calculated in several ways. One way is by using the relation that the distance between electrodes 401 and 403 equals to the conduction velocity of the nerve fiber multiply by the time shift. Person who skilled in the art may estimate the conduction velocity and by knowing the distant between the electrodes can calculate the time shift. Another possible manner for calculating the shift is to detect peaks 410 and 420 and measure the time difference between the said peaks. Another possible way is to calculate the cross correlation between the signals in Fig. 4B and Fig. 4C. The maximum peak of the cross correlation function versus time shift appears at the time shift 421.

Fig. 5A, 5B, 5C are schematic illustrations of examples for detecting a signal propagating in sensory nerve fibers, using cross correlation, in accordance with the present invention. Fig. 5A, presents a schematic drawing of an example of a C nerve signal, in accordance with the present invention. The width 501 of the signal is defined as the time difference between the two closest points of the same signal having a value about above the base (resting potential). Fig. 5B, presents a schematic drawing of an example of an A nerve signal, in accordance with the present invention. The width of the signal in Fig. 5B is marked 502. Width 501 is larger than width 502.

Fig. 5C illustrates a cross correlation function between the signal represented in Fig. 5A with itself. The value of peak 503 is its maximal value possible. In addition, on the same scale Fig. 5C also present a cross correlation function between the signal represented in Fig. 5A and the signal represented in Fig. 5B. Peak 504 is lower than peak 503. Person skilled in the art will appreciate that filtering out C nerve fiber action potentials can be done by choosing the action potentials that create a maximal cross correlation with a predetermined C nerve action potential. In addition, a certain threshold can be used for compensating a certain variation in the shape of the detected action potentials. Such threshold can be for example 0.4 normalized units as shown in Fig. 5C. Such example is for the purpose of illustration only and is not meant to be limiting.

Fig. 6 is a schematic illustration of the top view of the apparatus for measuring the electrical activity of nerve signals, in accordance with the present invention. The apparatus is capable of measuring, detecting and providing the level of sensory nerve activity in accordance with step 260 in Fig. 2. The apparatus housing 600 is preferably of round or elliptic shape for easy handling with one hand preferably. The apparatus comprises one or more rougher texture 601 having raised protrusions, small hemispheres and a like in order to enable a comfortable holding. In addition, a small picture of spine 602 is attached to the apparatus, in order to indicate that one side of the apparatus should be put above

the estimated end of the nerve, which is closer to the spine. Furthermore, the embodiment comprises see-through part 604 with a printed cross like shape 605 that would enable the person using the device to see the center of the pain source and also the skin upon which the device is used. This part could use either a
5 normal or a magnifying transparent material such as glass, Perspex, polycarbonate, plastic and a like. The apparatus further comprises a display 606 for displaying the sensory nerve activity, such as the pain level 607 and a number of the action potential per time unit 608. Pain level 607 can be chosen for example from the following table:

level	Description
1	No pain
2	Mild
3	Tolerable
4	Moderate
5	Severe
6	Disabling

10

The apparatus may further include a buzzer 609 for producing a certain sound while sensory nerve activity such as pain is detected and producing a different sound once the pain source is reached. The user of the device would move the device on the skin of the patient in order to localize and find the sensory
15 nerve activity source by maximizing the output signals either using the display or the buzzer or a combination thereof.

Figs. 7A, 7B are schematic illustrations of exemplary uses of the device measuring the electrical activity of nerve signals, especially pain level, in accordance with the present invention. One of the advantages of the present
20 embodiment is the ability to have an objective device to detect, and measure pain or other sensory nerve activity in subjects who are not able to communicate this information themselves such as babies, the mentally challenged, people who suffer from strokes, speech deficiency, people in a comma or other problems that

prevent communication with a physician. Fig. 7A shows a schematic illustration for the use of the device with babies or small children. The device 701 is placed on the child's body 702 where the pain source is suspected to be. The user moves the device 701 until pain source is identified or for measuring the level of sensory nerve activity along the paths of the nerve fibers. Another advantage of the device is that the principles of its operation can be applied to many other creatures rather than man.

Fig. 7B is a schematic example for the use of the device with animals. In the exemplary embodiment shown, the device 704 is placed on the body of a canine 703 where the pain source is suspected to be. The user moves the device 704 until the pain source is located or for measuring the level of sensory nerve activity along the paths of the nerve fibers.

Fig. 8A shows an illustrated examples for use of a device measuring the electrical activity of nerve signals, for measuring pain or the sensory nerve activity development over time. Fig. 8A is a schematic illustration of the manner of use of the device. Device 802 is attached to the subject's limb 801 using for example strips 800. The device 801 may record internally or transmit the results of the measurements made in the specific locations it is attached thereto over a period of time. Such period of time can be a few minutes, hours or even days. The device 802 may include a transmitter so that sensory nerve activity is measured and transmitted to a remote location and analyzed in real time. Fig. 8B is a graph showing the results of measurements made over a period of time. In the example shown in Fig. 8B the pain or sensory nerve activity level is plotted in a schematic graph showing the sensory nerve activity or pain level 803 versus time 804. The graph can show the effectiveness of treatment provided to the patient against pain. Prior to treatment at point 805, pain level is 5. At the beginning of the treatment at point 806, pain level decreases until pain level reaches level 2. At this point 807 the treatment ends and the pain level increases 808 to a level below the level before the treatment but higher than the level after the treatment was stopped for

example to level 3. The end of measurement is in point 809 when the device is removed from the subject.

Fig. 9 is an illustrated example for one possible use of the device for measuring the electrical activity of nerve signals, for selectivity disconnecting nerve fiber. The device 904 is located close to the body surface 901 detecting sensory nerve activity or a pain signal at nerve juncture 902, originating is from nerve 903. Detecting the accurate origin of the pain enable cutting nerve 903 using a cutting tool 904 such a laser, scalpel, freezing techniques and a like. The detection of the signal, such that when the device is moved and provides indication of the sensory nerve activity or pain, will allow the detection of the point of sensory nerve activity or pain origin.

Fig. 10 shows illustrated examples for transferring information form the apparatus for measuring an electrical activity of nerve signals, in accordance of with the present invention. As noted above the device may comprise a transmitter for sending data from the device to a remote device, such as a remote computer and the like. The device 1000 is transferring information measured and processed by the device 1000 to a remote computer or server 1011. The information may be stored during examination and later sent to the remote device, or sent to the remote device in real time. The method of transferring the information may include such means such as a wire 1002 or a wireless 1001 communication to a local or personal computer 1003 from which the data may be transferred to a remote computer or server 1011 using a wire or a wireless 1010 communication protocols and networks. Alternatively, wireless communication 1020 can be used directly between the remote computer 1011 and embodiment 1000 using local or wide area networks and known protocols such as TCP/IP and the like. In addition, a phone line 1030 may be used to connect between the device 1000 via phone 1031 and remote computer 1011. The data can be encrypted to a series of different sounds containing the required information to be sound by the embodiment buzzer. Than, using a phone handset the data will be sent to remote computer. A physician may monitor the sensory nerve activity or

pain levels in patients at home through the use of the device according to this embodiment.

Fig. 11 is a side view of a general illustration of an implantable apparatus that measures the electrical activity of nerves, with sensors that are in
5 close proximity to the nerve fibers in accordance with the present invention. Apparatus 1106 (shown not to scale) is connected to one or more electrodes or sensors 1108 in order to measure the electrical activity of nerve fiber 1104 in close proximity to this nerve. Apparatus 106 comprises the components described in detail in association with Fig. 1. The measures nerve activity is processes and
10 used as an input for the said implantable device operation. The implantable device can be implanted during a surgery operation or scope surgery operation or other minimal invasive surgery for bringing the apparatus 106 in proximity with a nerve fiber located inside the human body and remotely from the skin surface.

Persons skilled in the art will appreciate the many other alternatives
15 and embodiments for using the apparatus and method of the present invention and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather the scope of the present invention is defined only by the claims which follow.

20

CLAIMS

I / we claims:

1. An apparatus for measuring the non-stimulated activity of a plurality of sensory nerve fibers, the apparatus comprising:
 - 5 at least two sensors in proximity to the nerve fibers for measuring signals passing through the sensory nerve fibers, the sensors are spaced apart such that the measurements can be correlated; and
 - a pattern recognition device for correlating the measurements in a time difference or time difference range reflecting a predetermined velocity range.
- 10 2. The apparatus of claim 1 further comprising:
 - an amplifier for amplifying the signals measured by the at least two sensors; and
 - a filter for filtering the signal measured by the at least two
- 15 sensors.
3. The apparatus of claim 1 wherein the pattern recognition device counts the number of action potential spikes passing through the nerve fibers.
4. The apparatus of claim 1 wherein the pattern recognition device
- 20 further sums all the correlation value points measured and correlated.
5. The apparatus of claim 1 wherein the correlation is performed through cross correlating the measurements and calculating the conduction velocity distribution.
- 25 6. The apparatus of claim 1 further comprising an output device for providing an output signal to a user, said output signal showing the sensory nerve activity signal level.
7. The apparatus of claim 1 wherein the distance between the at least two sensors is less than 3 centimeters.

8. The apparatus of claim 1 wherein the filter is a high or low band pass or notch filter.
9. The apparatus of claim 1 wherein the sensors are active or passive electrodes.
- 5 10. The apparatus of claim 1 further comprising a communication device for transmitting the measurements or processed measurements to a remote device.
11. The apparatus of claim 1 wherein the apparatus is an implantable device or a device used in inside the body and remotely to the skin.
- 10 12. The apparatus of claim 1 further comprising an wireless device for sending the activity level to a remote device for monitoring patients nociception level.
- 15 13. A method for measuring the non-stimulated activity of a plurality of sensory nerve fibers, the method comprising the steps of:
- receiving a nerve potential activity signal through at least two sensors;
- amplifying the received signal;
- 20 style="padding-left: 40px;">filtering the amplified signal for detecting the specific action potential signal from the entirety of the signal received and amplified;
- determining and storing the signal associated with sensory nerve signals from the signals filtered by cross correlating between two predetermined signal; and
- 25 style="padding-left: 40px;">calculating the activity of the signal associated with sensory nerve signals through the use of an operator for determining that a sensory nerve action potential is present
14. The method of claim 13 wherein the step of determining comprises recognizing the pattern of an A or C nerve action potential.

15. The method of claim 13 wherein the operator can be an integral of the conduction velocity distribution calculation.
16. The method of claim 13 wherein the operator can be an integral of the conduction velocity distribution calculation between two velocities of two signals received, corresponding a sensory nerve velocity range.
17. The method of claim 13 wherein the operator is a comparison of the conduction velocity distribution to a predetermined histogram.
18. The method of claim 13 further comprising the step of determining whether the result of the operator indicates a valid signal.
19. The method of claim 13 further comprising the step of presenting an output to a user.
20. The method of claim 13 further comprising the step of processing the next active signal.
21. The method of claim 19 further comprising the step of incorporating predetermined parameters relating to a user or a patient with the output signal such that in accordance with such parameters the output signal may vary.
22. The method of claim 13 wherein cross correlating between two predetermined signal comprises cross correlating between a signal measured by the at least two sensors and a template predetermined signal.
23. The method of claim 13 wherein cross correlating between two predetermined signal comprises cross correlating between signals measured by the at least two sensors.
24. The method of claim 13 wherein cross correlating between two predetermined signal comprises the steps of receiving the longitude distance between the at least two sensors such that the signal received in the two sensors to be correlated; calculating the expected time difference for a signal to arrive in a predetermined velocity

- range wherein the maximal time difference is equal to the time difference divided by the maximum predetermined speed range for the signal while the minimal time difference is equal to the time difference divided by the minimum predetermined speed range for the signal; receiving measurements from the at least two sensors; calculating the cross correlation between the measurements of the at least two sensors; calculating an integral of the cross correlation results between the minimal and maximal time differences.
- 5
25. The method of claim 24 further comprising the step of summing the cross correlation values an area proportional to the activity of a nerve signal in the signal minimum and maximum speed range.
- 10
26. The method of claim 24 further comprising the step of storing each measurement and each result.
27. The method of claim 24 wherein the calculation of the cross correlation is performed for at least the minimal and maximal time difference.
- 15
28. The method of claim 13 wherein cross correlating comprises the steps of acquiring an action potential; cross correlating the action potential with a template having a first width; cross correlating the action potential with a template having a second width; determining whether the second width is not smaller than a predetermined minimum width value and if no determining if a maximum point of the cross correlation with the second width is greater than a maximum point of the cross correlation with the first width.
- 20
29. The method of claim 13 wherein cross correlating between two predetermined signal comprises the steps of initializing the action potential, time of measurement and first and second width variables; updating the first and second width variables; acquiring an action potential; cross correlating the action potential with a template having a first width; cross correlating the action potential with a
- 25
- 30

template having a second width; determining whether the second width is not smaller than a predetermined minimum width value and if no determining if a maximum point of the cross correlation with the second width is grater than a maximum point of the cross correlation with the first width.

30. The method of claim 29 further comprising the step of decreasing the first and second width if the maximum point of the cross correlation with the second width is grater than the maximum point of the cross correlation with the first width further.

31. The method of claim 29 further comprising the step multiplication of the first and second width if the maximum point of the cross correlation with the second width is not grater than the maximum point of the cross correlation with the first width further.

32. The method of claim 29 further comprising the step of obtaining the next action potential.

33. The method of claim 29 further comprising the step of determining that the cross correlation with the template having the first width is the correct calculation and further calculating the maximum point of the cross correlation.

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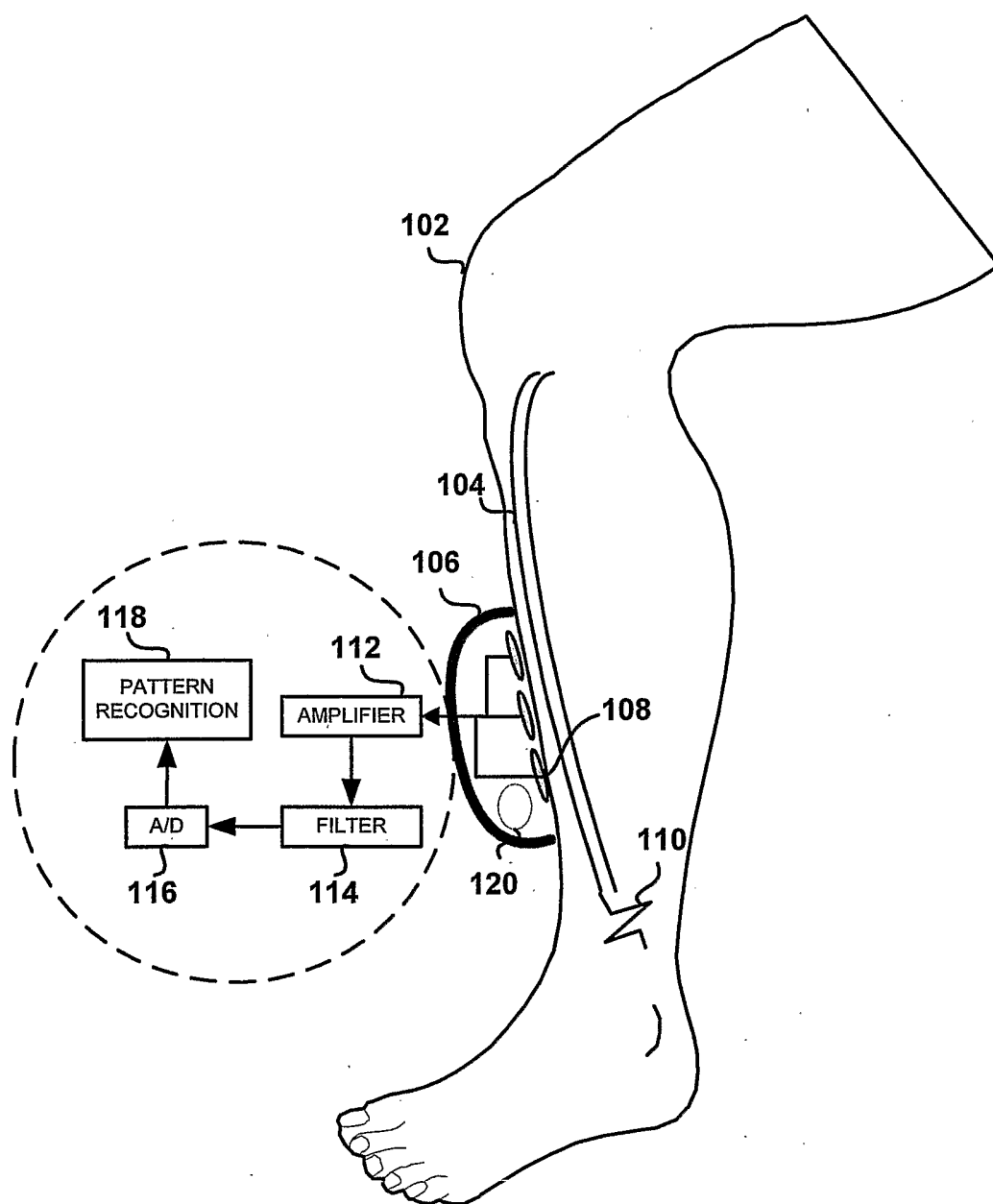
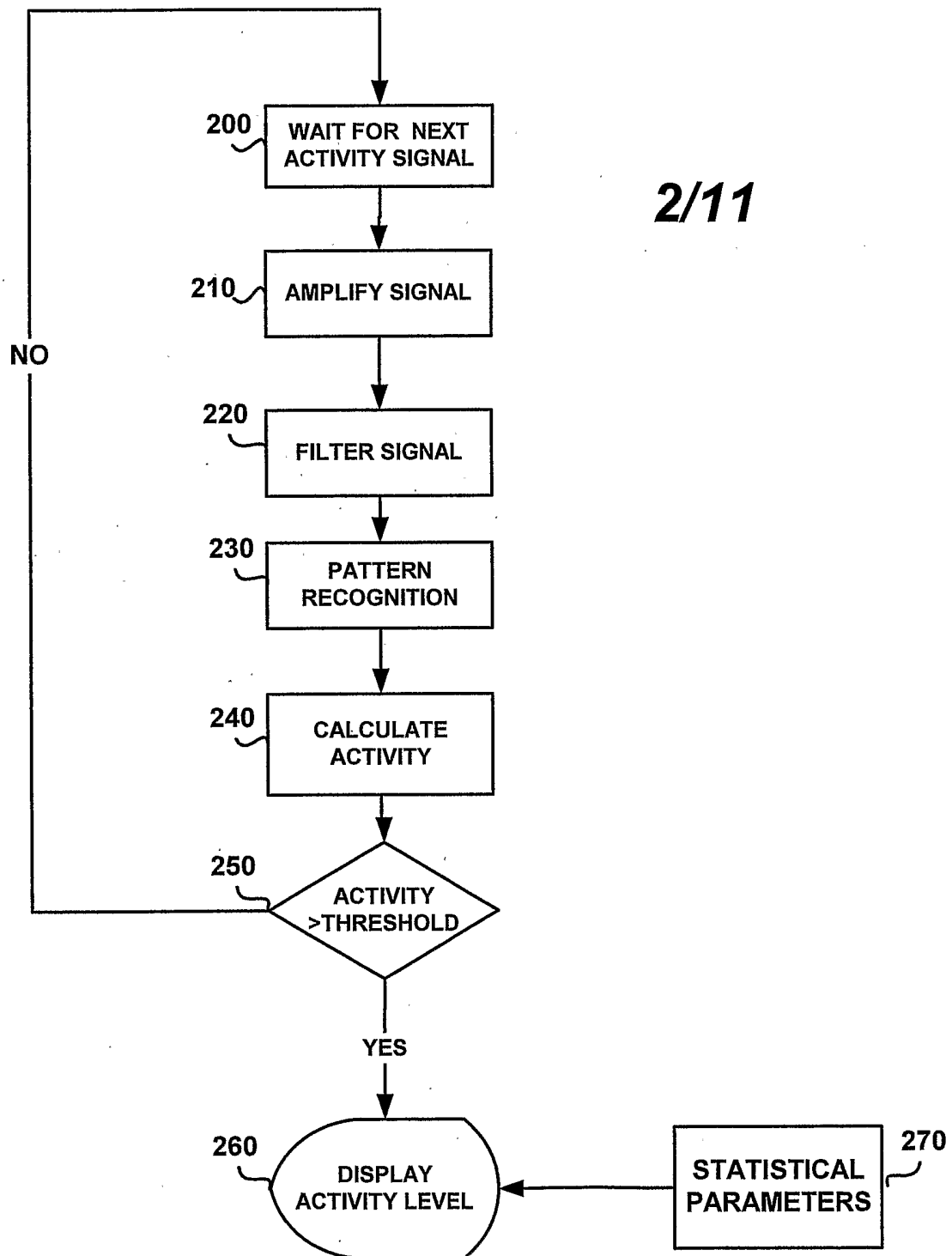
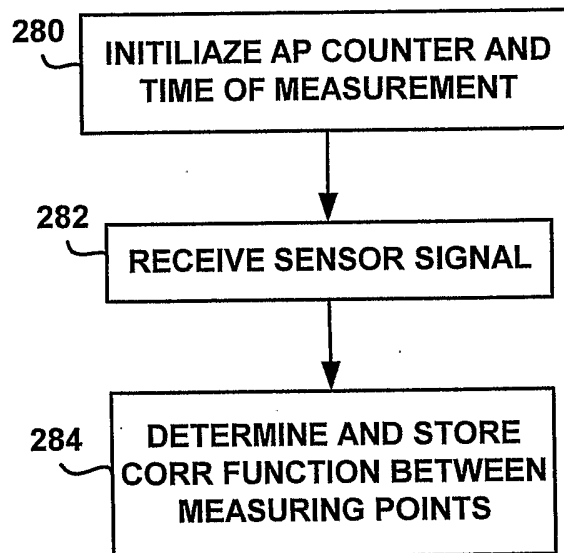
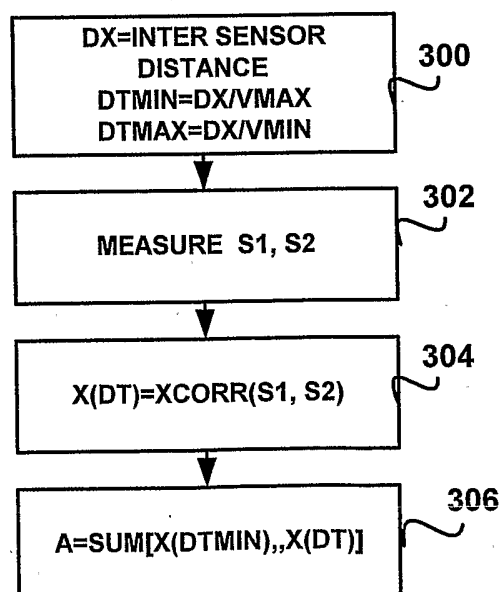


FIG. 1

**FIG. 2**

3/11**FIG. 3A****FIG. 3B**

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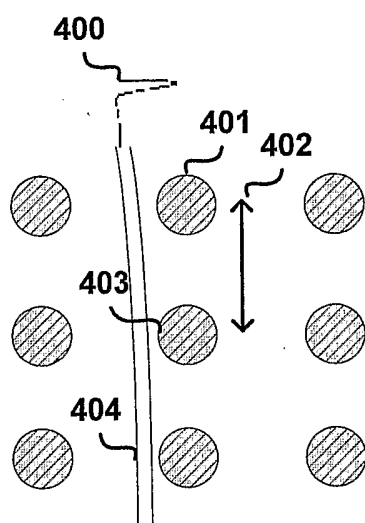


FIG. 4A

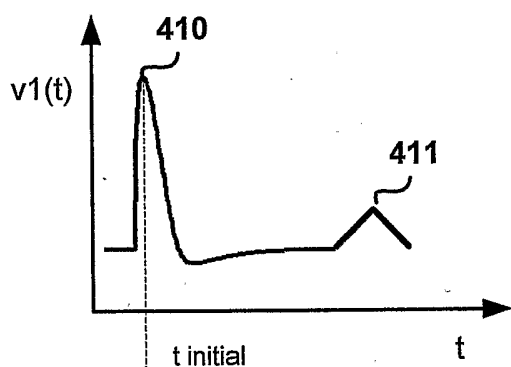


FIG. 4B

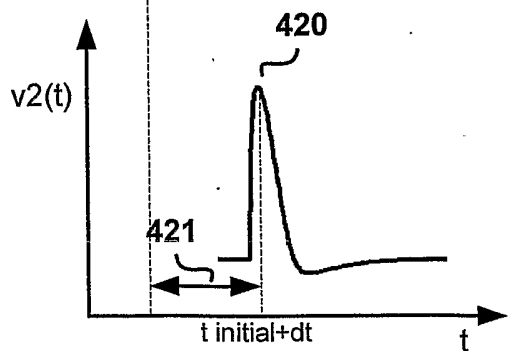


FIG. 4C

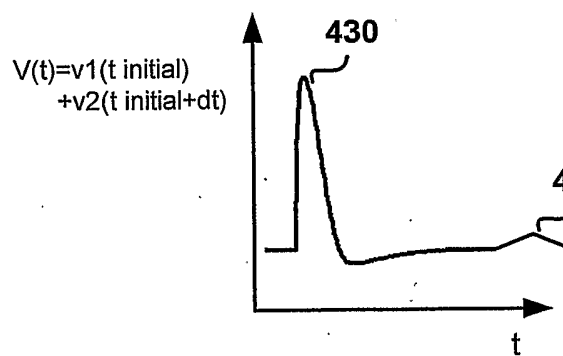


FIG. 4D

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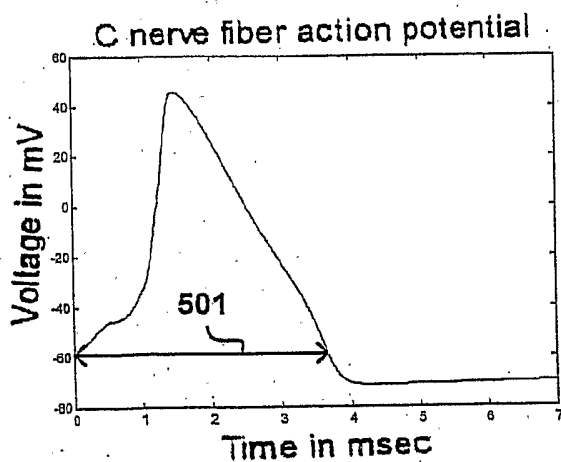


FIG. 5A

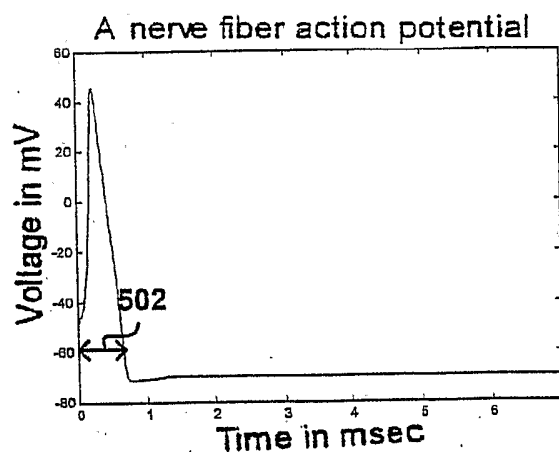


FIG. 5B

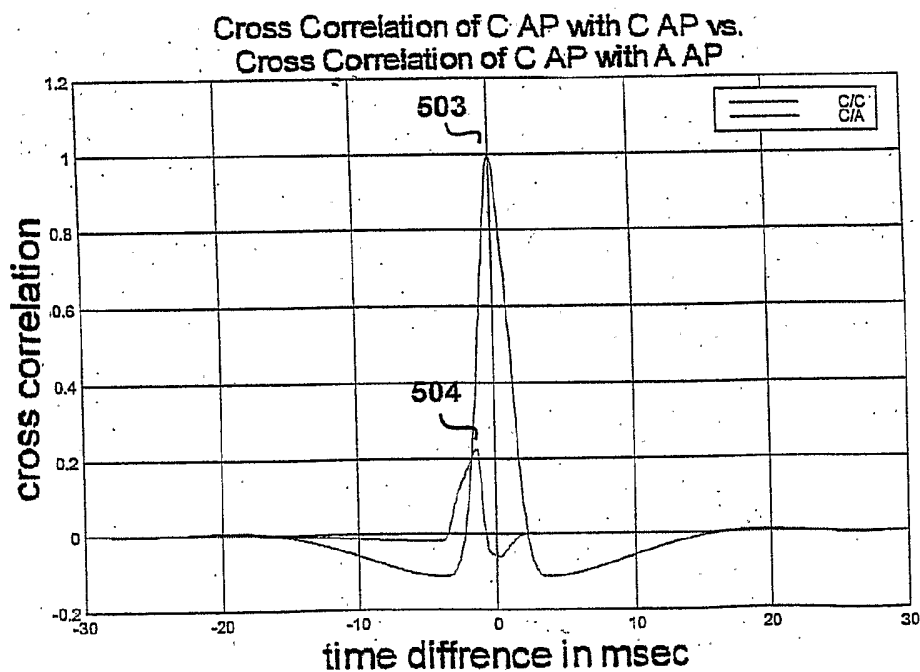


FIG. 5C

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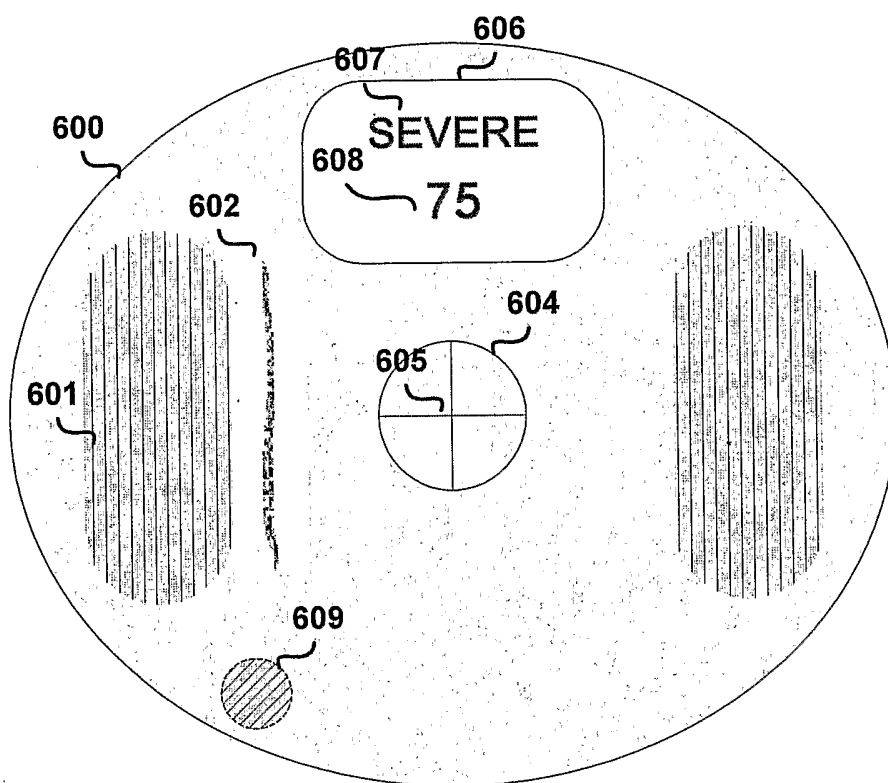


FIG. 6

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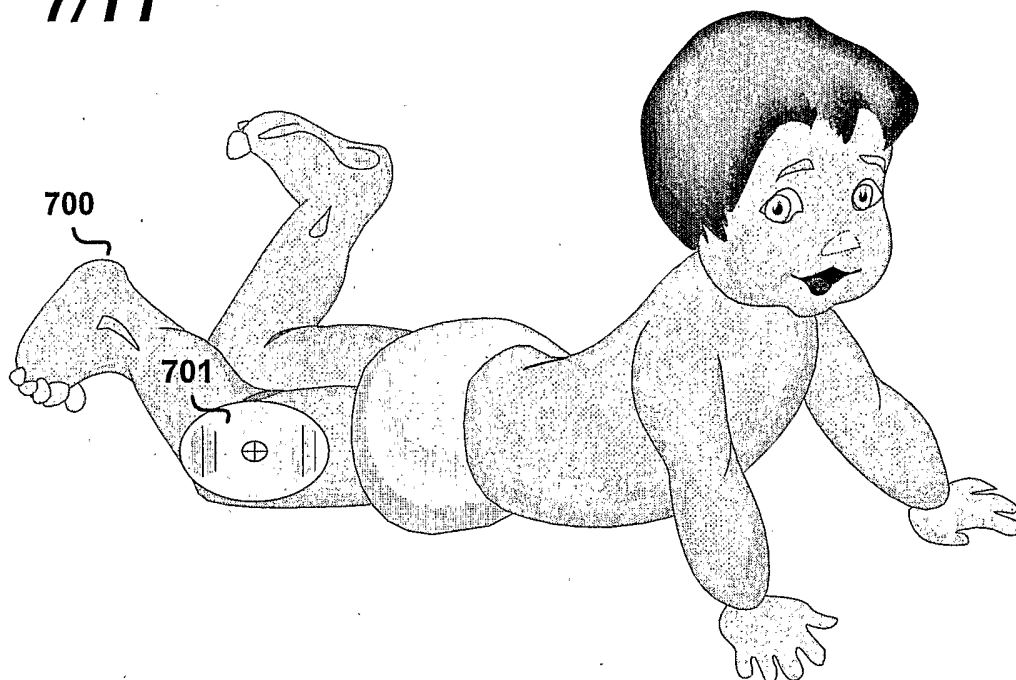


FIG. 7A

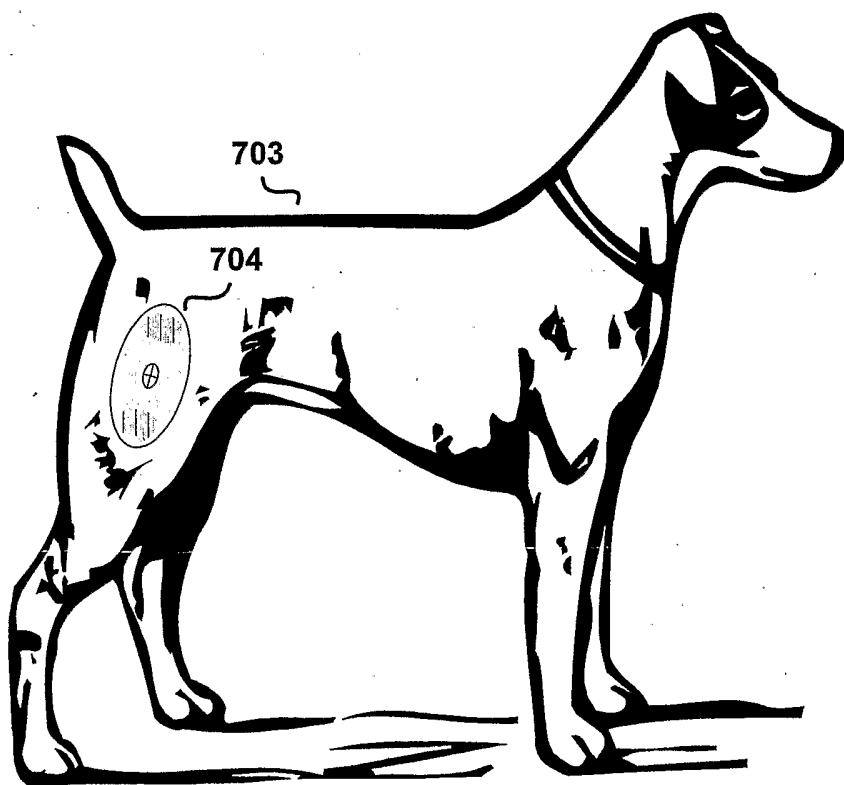


FIG. 7B

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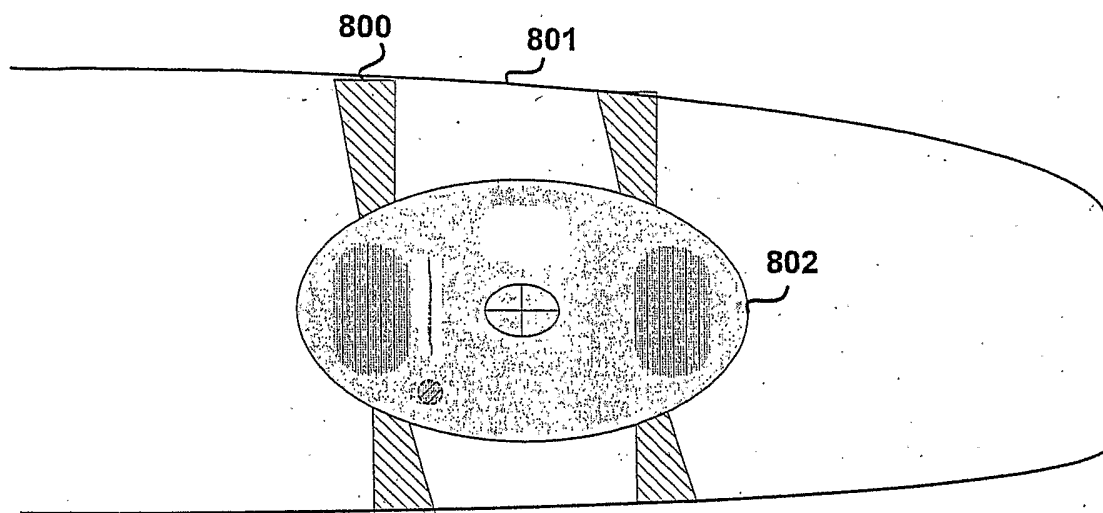


FIG. 8A

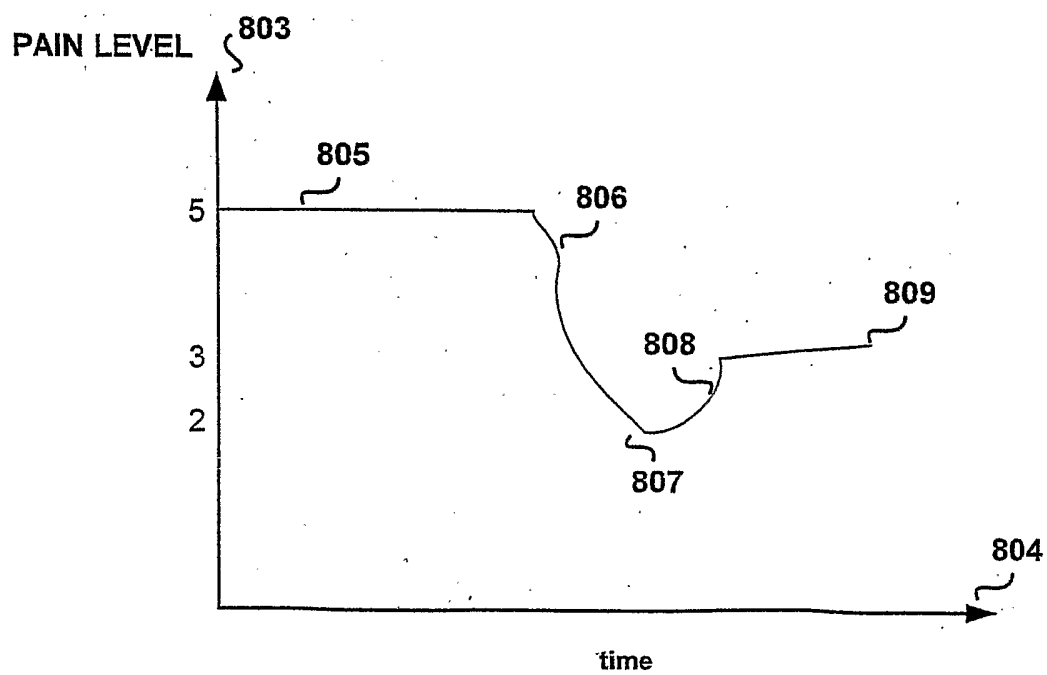


FIG. 8B

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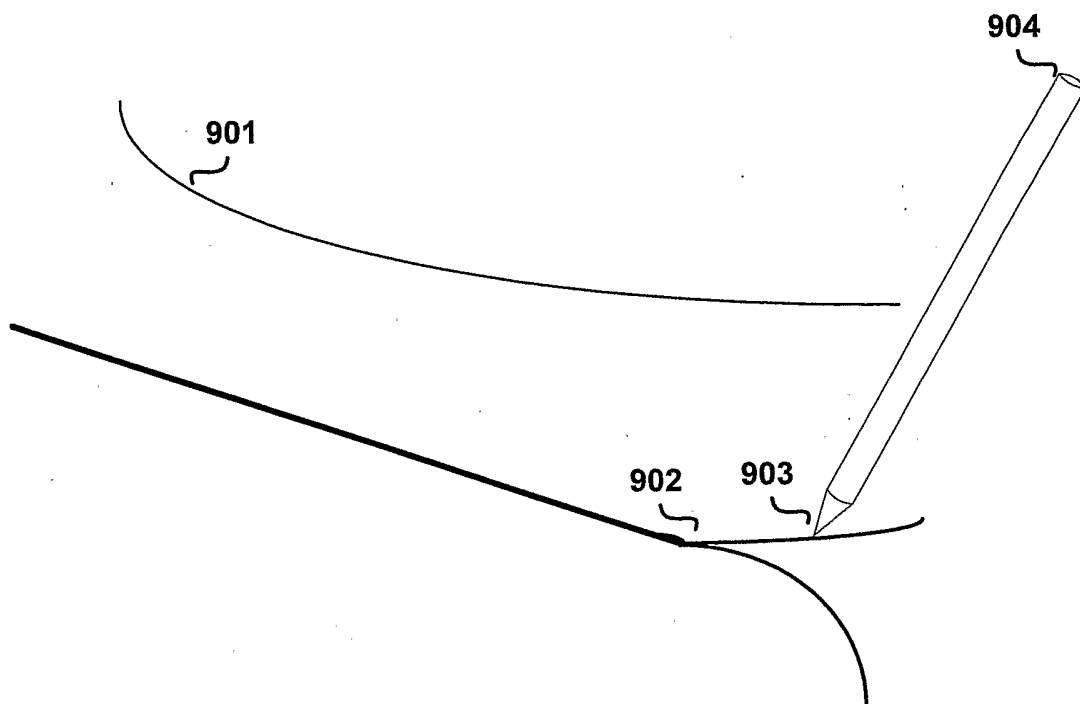


FIG. 9

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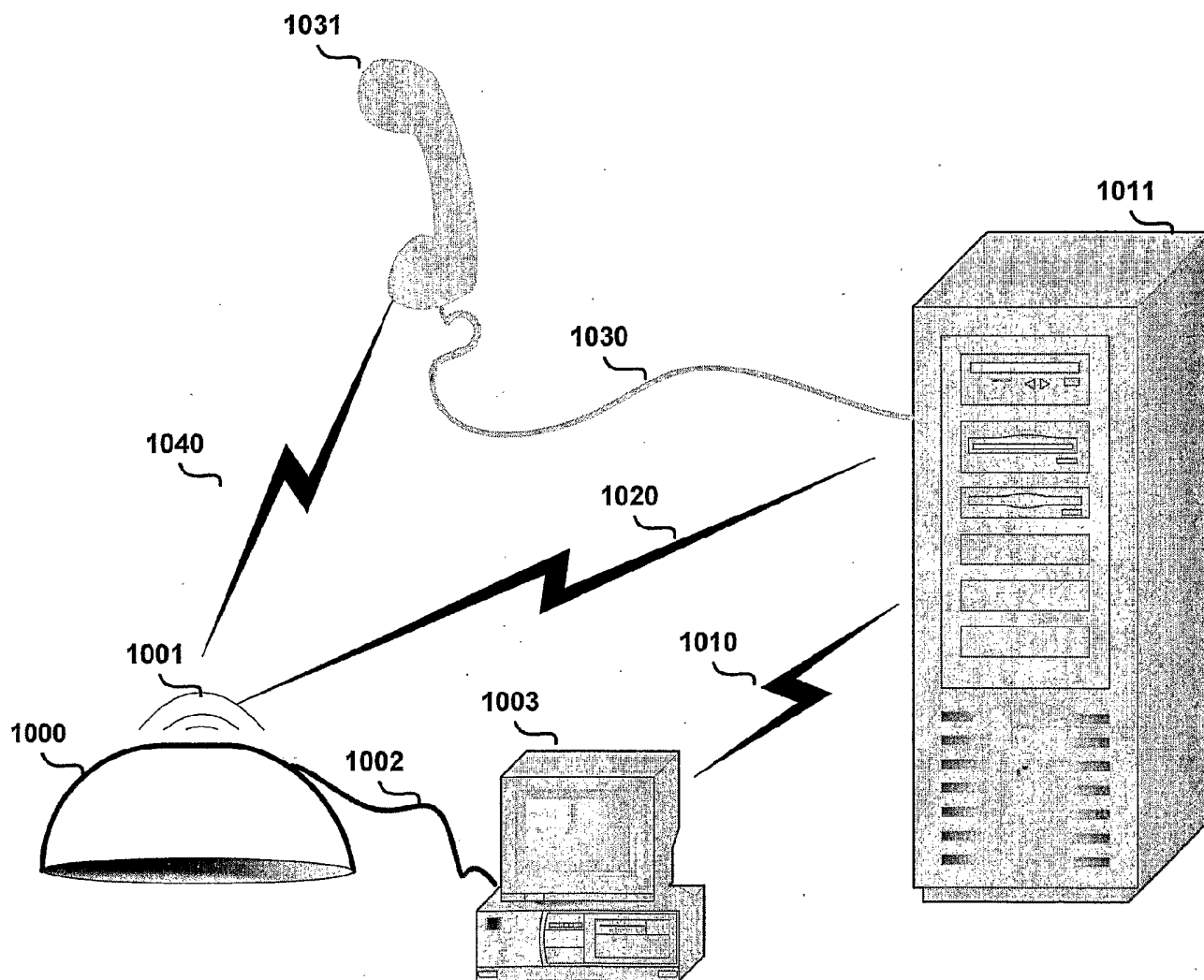


FIG. 10

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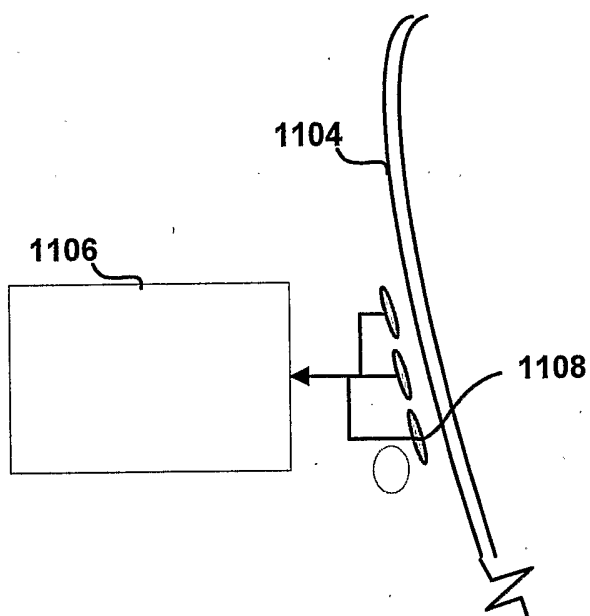


FIG. 11