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(54) **DISPOSABLE SENSOR FOR NEUROMUSCULAR TRANSMISSION MEASUREMENT**

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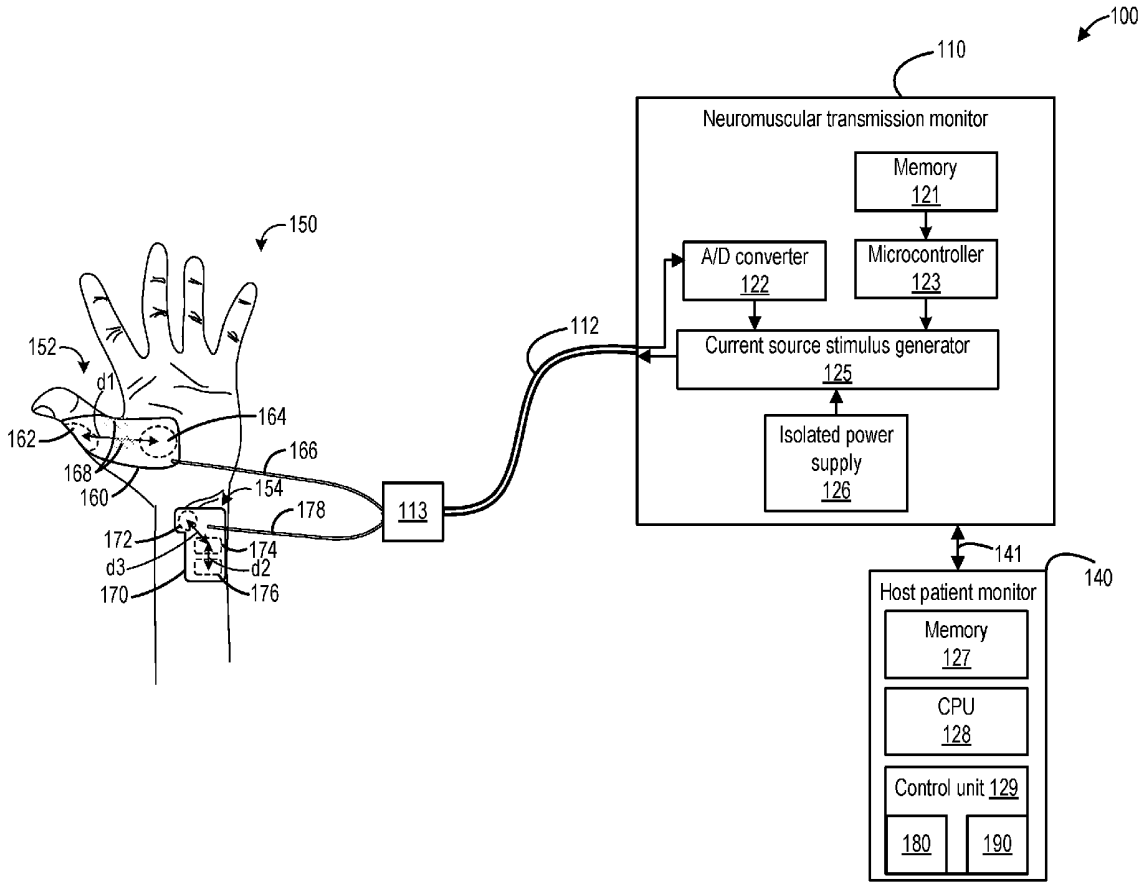
(57) **ABSTRACT**

Sensors are provided for monitoring neuromuscular blockade in patients. In one embodiment, a sensor includes a first flexible substrate including a sensing element for measuring patient response to a stimulus, a second flexible substrate for providing the stimulus, the second flexible substrate including at least two electrodes, the first flexible substrate not connected to the second flexible substrate, and a common connector coupled to both the first flexible substrate and the second flexible substrate, the connector configured to couple to an NMT monitoring device.



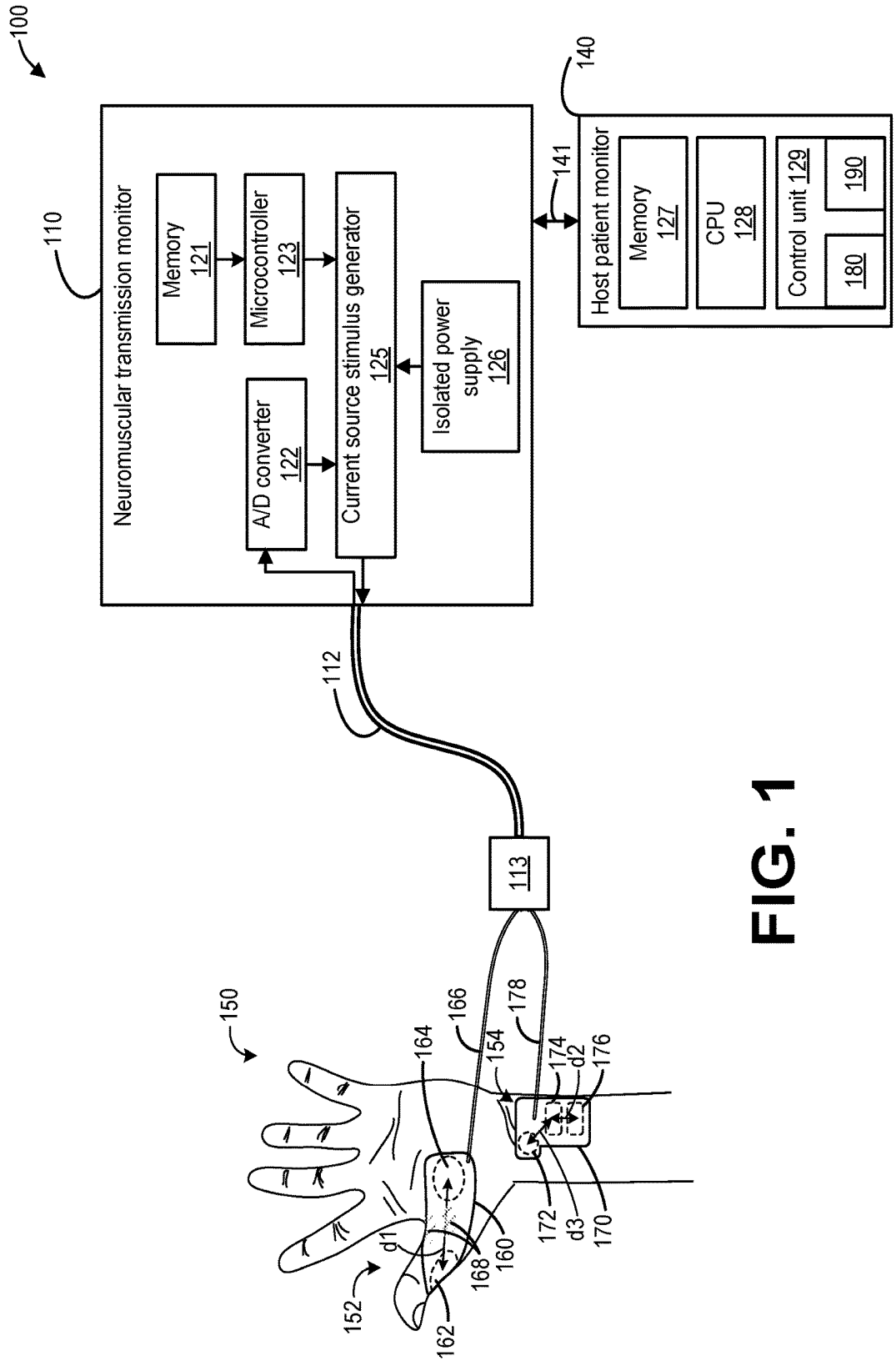
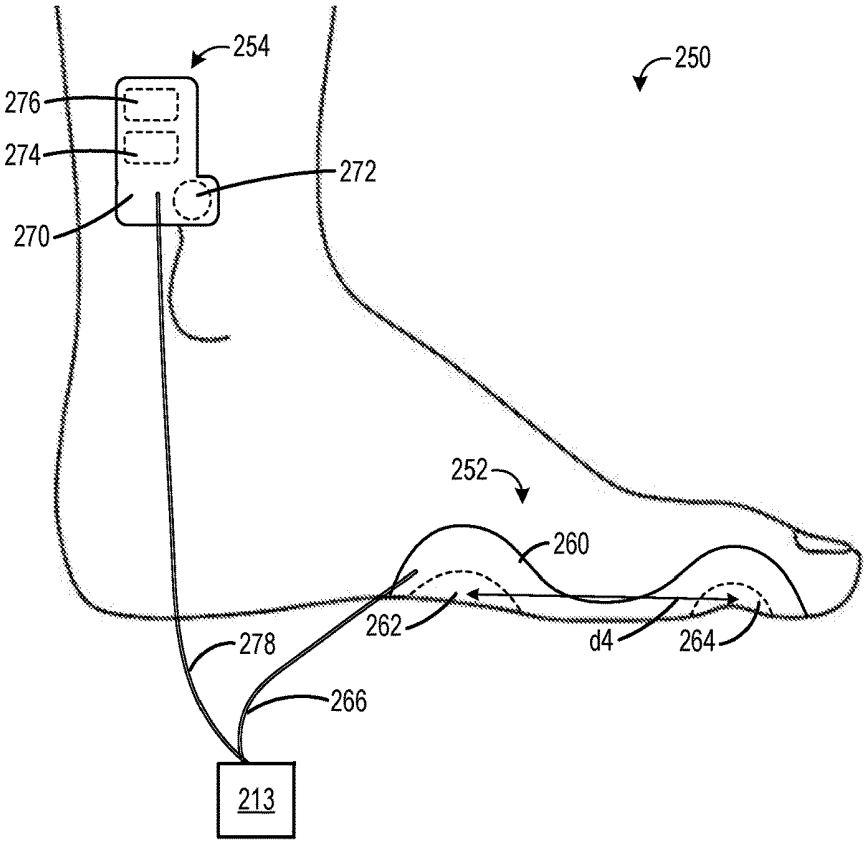

100
110
Neuromuscular transmission monitor
Memory 121
Microcontroller 123
Current source stimulus generator 125
A/D converter 122
Isolated power supply 126
140
141
Host patient monitor
Memory 127
CPU 128
Control unit 129
190
180
112
113
150
152
154
160
162
164
166
168
170
172
174
176
178
d1
d2
d3

FIG. 1


254
250
276
274
272
270
252
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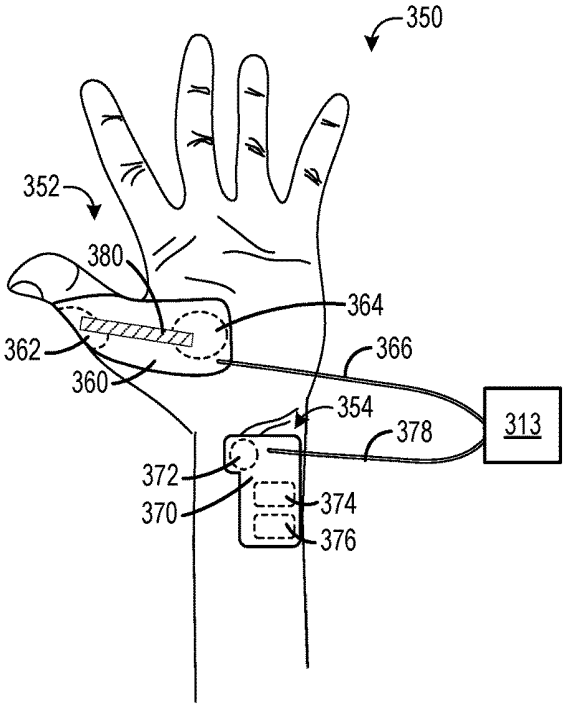
262
d4
264
278
266
213

FIG. 2


350
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380
364
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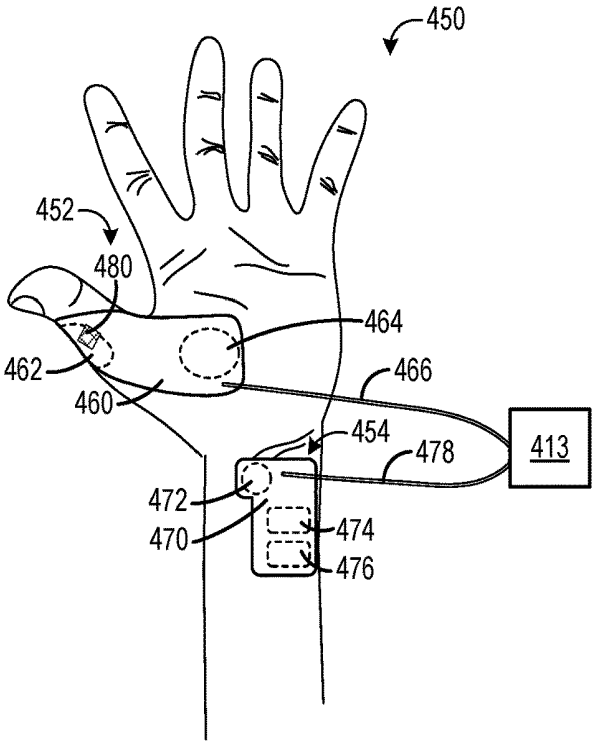
374
376

FIG. 3


450
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464
462
466
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413
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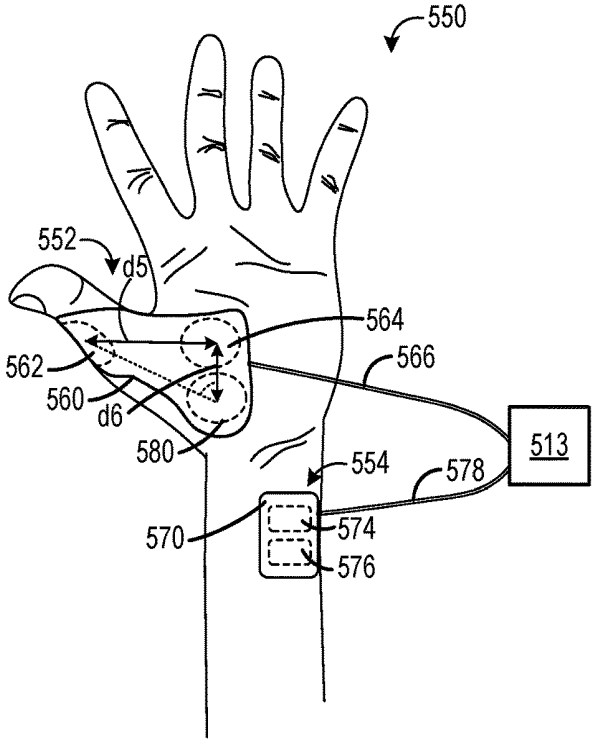
470
476

FIG. 4


550
552
d5
564
562
566
560
d6
580
513
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578
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574
576

FIG. 5

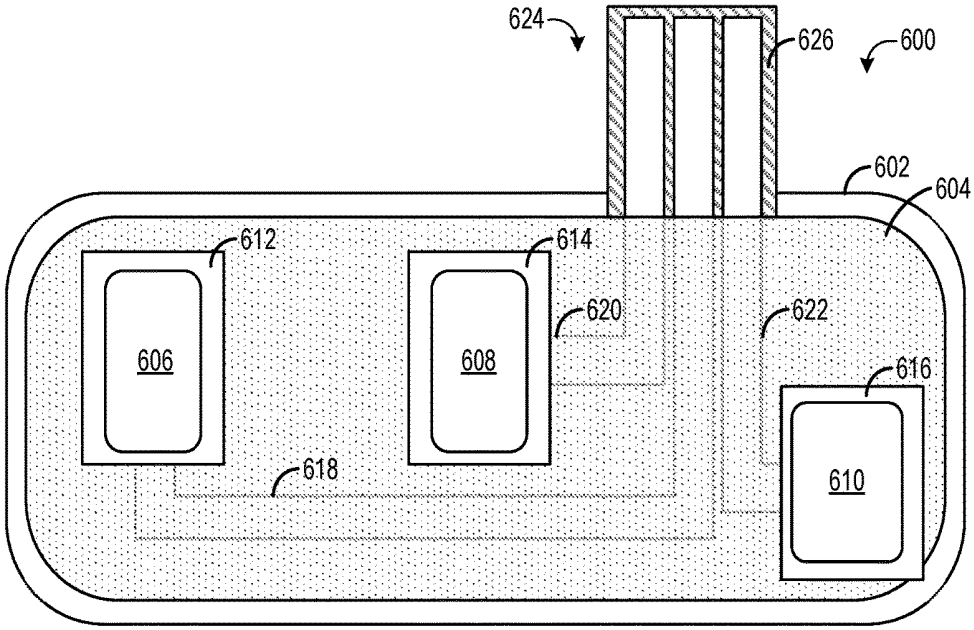

FIG. 6

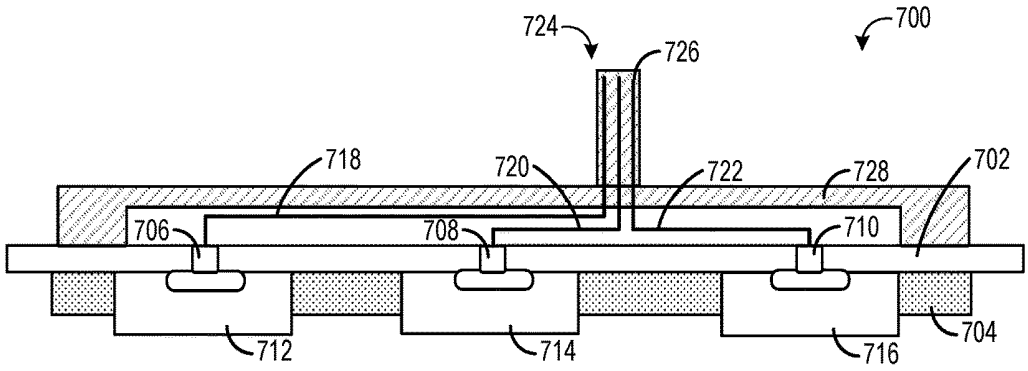

FIG. 7

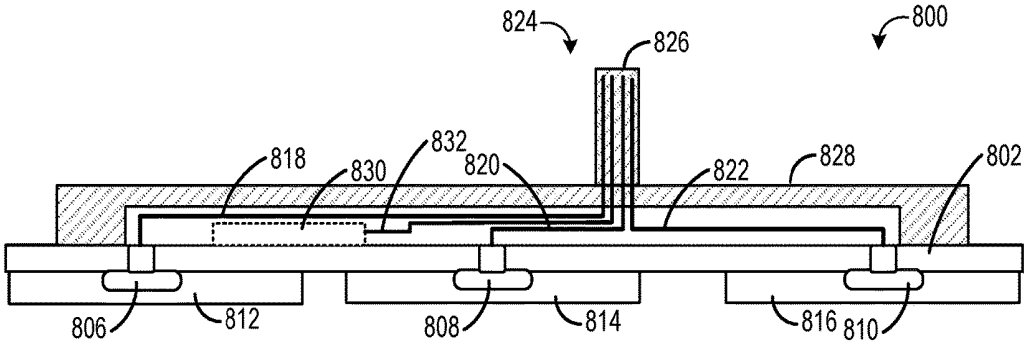

FIG. 8

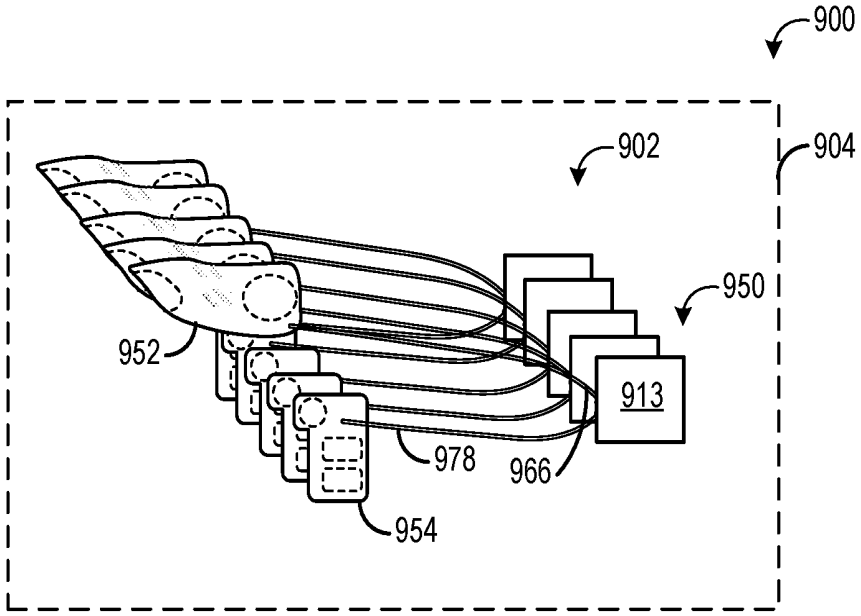

FIG. 9

DISPOSABLE SENSOR FOR NEUROMUSCULAR TRANSMISSION MEASUREMENT

FIELD

[0001] Embodiments of the subject matter disclosed herein relate to medical devices, and more particularly, to monitoring neuromuscular transmission during a surgical procedure.

BACKGROUND

[0002] Neuro Muscular Transmission (NMT) is the transfer of an impulse between a nerve and a muscle in the neuromuscular junction. NMT may be blocked in a patient undergoing a surgical procedure, for example, by neuromuscular blocking agents/drugs, which may cause transient muscle paralysis and prevent the patient from moving and breathing spontaneously. Thus, the level of neuromuscular block may be monitored to ensure appropriate block is provided for the given procedure.

BRIEF DESCRIPTION

[0003] In one embodiment, a sensor includes a first flexible substrate including a sensing element for measuring patient response to a stimulus, a second flexible substrate for providing the stimulus, the second flexible substrate including at least two electrodes, the first flexible substrate not connected to the second flexible substrate, and a common connector coupled to both the first flexible substrate and the second flexible substrate, the connector configured to couple to an NMT monitoring device.

[0004] It should be understood that the brief description above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0006] FIG. **1** shows an example neuromuscular transmission (NMT) monitoring system including a first embodiment of an NMT sensor configuration.

[0007] FIG. **2** shows a second embodiment of an NMT sensor configuration.

[0008] FIG. **3** shows a third embodiment of an NMT sensor configuration.

[0009] FIG. **4** shows a fourth embodiment of an NMT sensor configuration.

[0010] FIG. **5** shows a fifth embodiment of an NMT sensor configuration.

[0011] FIG. **6** shows an example stimulating structure with printed leads.

[0012] FIGS. **7-8** show example stimulating structures with wire leads.

[0013] FIG. **9** shows an example kit of NMT sensors.

DETAILED DESCRIPTION

[0014] The following description relates to various embodiments of a neuromuscular transmission (NMT) monitoring system configured to monitor an amount of neuromuscular blockage after the administration of muscle relaxants in patients during surgery. NMT is the transfer of an impulse between a nerve and a muscle in the neuromuscular junction. NMT may be blocked by neuromuscular blocking agents/drugs, which may cause transient muscle paralysis and prevent the patient from moving and breathing spontaneously. Additionally, muscle relaxation may be used during general anesthesia to enable endotracheal intubation and to provide the surgeon with optimal working conditions. At the end of a surgical procedure, the neuromuscular block is reversed such that neuromuscular activity may be returned to normal and that the patient may be able to breathe unassisted, before the removal of the endotracheal intubation (i.e. extubation). Thus, appropriate assessment of the degree of NMT block may be used for ensuring proper timing of intubation and for guiding intraoperative administration of neuromuscular blocking agents, maintaining a desired degree of intraoperative neuromuscular block, and ultimately preventing the occurrence of residual muscle paralysis.

[0015] An NMT monitor may be used to monitor muscle response to electrical stimulation of a motor nerve (e.g., the ulnar nerve). For example, an electrical stimulus may be provided at the ulnar nerve near the wrist and the response of the adductor pollicis muscle near the thumb may be monitored. In clinical settings, a nerve stimulator is attached to a motor nerve of the patient and an electrical stimulation current is applied to the patient before induction of anesthesia. A baseline value for the muscle response is recorded by the NMT monitor and used to normalize the muscle response once the muscle relaxant is administered. The evoked muscle responses may then be monitored via several methods, including the measurement of electrical response of the muscle (electromyography (EMG)) and the measurement of the degree of distortion or bending in a piezoelectric film attached to the muscle (kinemyography (KMG)). KMG measures mechanical activity based on the distortion or bending of the piezoelectric polymer strip placed within the bending sensor between the thumb and forefinger. In EMG, multiple electrodes may be used to record the compound muscle potential stimulated by the stimulus generator.

[0016] Thus, in EMG-based NMT monitoring systems, multiple sensing elements as well as a stimulating element are placed on the hand or foot of a patient. Each sensing element and stimulating element may be placed on the patient individually, and then the leads coupling each sensing element and stimulating element to the NMT monitoring system are individually coupled to the respective sensing or stimulating element. Therefore, attaching the EMG sensing and stimulating elements to a patient may be time consuming. Further, the EMG configuration described above be difficult to disinfect. While the KMG-based NMT monitoring system described above may include fewer sensing elements, KMG-based NMT monitoring may not be as accurate as EMG-based NMT monitoring.

[0017] According to embodiments disclosed herein, an NMT sensor for use in an NMT monitoring system may include a sensing structure comprised of a sensing element coupled to a single flexible substrate. The flexible substrate may be shaped to correspond to the anatomy to which the

substrate is to be attached (e.g., a hand). The sensing element may include two or more sensing electrodes, with the sensing electrodes coupled to the substrate at select positions such that the sensing electrodes will be coupled to target anatomy once the sensing structure is attached to a patient. In other examples, the sensing element may include a piezoelectric element, an accelerometer, or combinations thereof (e.g., sensing electrodes and a piezoelectric element or accelerometer). The NMT sensor may also include a stimulating structure comprised of stimulating electrodes coupled to a separate flexible substrate that is not attached to or a part of the sensing structure. Each of the sensing structure and stimulating structure may include a respective electric lead (e.g., cable) that join at a common connector configured to electrically couple (e.g., via a trunk cable) the sensing structure and stimulating structure to an NMT monitoring system. By separating the stimulating structure from the sensing structure, additional flexibility in the placement of the stimulating electrodes and sensing element may be provided and any forces acting on the trunk cable (such as due to patient movement or inadvertent movement of the trunk cable by a clinician) may be split between the two separate leads, thus lowering the likelihood the sensing structure or stimulating structure may be accidentally removed from the patient. Further still, the sensing structure and stimulating structure (including the two leads and the common connector) may be disposable, thus eliminating the need to disinfect any of the components of the NMT sensor after patient use and reducing the risk of cross-contamination among patients.

[0018] An example of a neuromuscular transmission monitoring system is provided in FIG. **1**. The NMT monitoring system may include an NMT sensor adapted to be attached to a hand of a patient and comprising a stimulating structure configured to stimulate one or more nerves of a patient and a sensing structure that may include one or more electro-sensors which detect electrical activity of a muscle (referred to as an EMG sensor), where the electro-sensors are coupled to a single flexible substrate. The NMT monitoring system of FIG. **1** also includes a computing system including instructions to monitor neuromuscular block in patients in response to output from the NMT sensor. FIGS. **2-5** show various embodiments for the NMT sensor, including an NMT sensor with electro-sensors adapted to be placed on a foot of a patient (FIG. **2**), an NMT sensor with a piezoelectric mechano-sensor as well as electro-sensors and adapted to be placed on a hand of a patient (FIG. **3**), an NMT sensor adapted to be placed on a hand of a patient and including electro-sensors and an accelerometer (FIG. **4**), and an NMT sensor adapted to be placed on a hand of a patient and including electro-sensors, with a grounding electrode present on the same flexible substrate as the electro-sensors (FIG. **5**), rather than the grounding electrode being present on the same flexible substrate as the stimulating electrodes (as shown in FIGS. **1-4**). The flexible substrates with sensing elements attached thereto may be manufactured according to a suitable configuration, including with printed leads (as shown by FIG. **6**) or with lead wires (as shown in FIGS. **7** and **8**).

[0019] FIG. **1** illustrates an example neuromuscular transmission (NMT) monitoring system **100** that is configured to monitor neuromuscular activity via an EMG-based NMT sensor. However, components of NMT monitoring system **100** may also be used to monitor neuromuscular activity via a KMG-based NMT sensor. NMT monitoring system **100** includes a neuromuscular transmission monitor **110** which is communicatively coupled to a host patient monitor **140** via a communication link **141**. The neuromuscular transmission monitor **110** is configured to be coupled to a stimulating structure **154** (described in more detail below), for providing stimulation output (e.g., electrical stimuli) of varying type and frequency to the patient. The NMT monitor **110** also includes at least one input configured to couple to a sensing structure **152** that includes one or more elements for monitoring the evoked muscle response in response to the electrical stimuli provided by the neurostimulators. The signals detected by the transducers may then be converted into electrical signals by the A/D converter **122** of neuromuscular transmission monitor **110**.

[0020] The amount of electrical stimulation provided to the stimulating structure **154** is controlled by a current stimulus generator **125** which receives command signals from microcontroller **123**. Microcontroller **123** is linked to the user interface of control unit **129** of host patient monitor **140**, which comprises of a display unit **190** and buttons/knobs **180**. The type and frequency of the stimulation output may be adjusted manually by the user (manual mode) or be automatically chosen by the system (automatic mode). In one example, the type and frequency of the stimulation output may be adjusted by the user via pressing buttons or knobs **180** on the patient host monitor **140**.

[0021] A power supply (not shown) may supply electricity to an isolated power supply **126** which in turn provides power to current source stimulus generator **125**. The microcontroller **123** may be connected to the current source stimulus generator **125** to adjust the amount of electric current provided to the stimulating structure **154**. The current stimulus generator **125** may generate different types of neurostimulation including train-of-four (TOF), single twitch (ST), double burst (DBS), post tetanic count (PTC), current range (e.g., 1-70 mA with 1 mA steps), pulse width/frequency (e.g., 100, 200, 300 μs, or 1 Hz, 2 Hz, etc.). Further, the types of neurostimulation may be chosen via a manual or an automatic stimulating mode. If a manual stimulating mode is chosen, then the user may input the desired neuromuscular stimulating types, current range, and pulse width and/or frequency via pressing button **180** of the host patient monitor **140**, for example. Alternatively, if a touch-screen is used as the display unit (e.g., display unit **190** of host patient monitor **140**), then user input may be provided via touch input to the touch-screen on the display unit.

[0022] If an automatic neurostimulation mode is chosen, microcontroller **123** of neuromuscular transmission monitor **110** may select a first neurostimulation type as its default setting, such as TOF stimulation, and based on the muscle response signals received from the sensing structure **152**, the microcontroller may determine the optimal neurostimulation type, and report the muscle response signals to the user by displaying graphs and numbers (e.g., via display unit **190** of host patient monitor **140**). The display unit **190** may display the muscle response data/information to the user and may also include alarm signals/message for alerting the user of potential sensor error.

[0023] Additionally, neuromuscular transmission monitor **110** may be connected to a host patient monitor **140** through a communication link **141**. Host patient monitor **140** may include memory **127**, CPU **128**, and control unit **129**.

Memory **127** may have similar functions as memory **121**. Control unit **129** may include control buttons/knobs **180** and display unit **190**. The control buttons and knobs of control unit **129** may be configured to allow for user input. The display unit **190** may be configured to receive touch input from a user.

[0024] NMT sensor **150** includes a sensing structure **152** and a stimulating structure **154**. Sensing structure **152** includes a flexible substrate **160** to which a sensing element is coupled. In the example depicted in FIG. **1**, the sensing element includes two electrodes, a first electrode **162** and a second electrode **164**. Flexible substrate **160** may be comprised of a suitable flexible, non-conductive material such as silicon, polyethylene terephthalate (PET), polyethylene (PE), or other thermoplastic resins. Flexible substrate **160** may be shaped to conform to the underlying anatomy (e.g., hand) and thus include a first region configured to be placed on top of a suitable region of the thumb, such as the distal interphalangeal joint of the thumb, for example, and a second region configured to be placed on top of a suitable region of the palm, such as the adductor pollicis in the thenar eminence, for example, with a connecting region coupling the first and second regions. The connecting region may be shaped to allow movement of the thumb relative to the palm (e.g., the connecting region may be countered to match the contour of the hand where the thumb extends from the palm) and may bend to accommodate differences in patient size, anatomy, and movement. In some examples, the connecting region (and/or other areas of the flexible substrate) may include areas of additional flexibility, such as areas **168**. These areas may be comprised of a different material than the rest of the flexible substrate, where the different material is more flexible than the rest of the flexible substrate. The areas may accommodate flexing, bending, etc., of the flexible substrate in areas expected to be subject to movement. First electrode **162** may be positioned on the first region and second electrode **164** may be positioned on the second region. First electrode **162** and second electrode **164** may be spaced apart by a distance d**1** (e.g., d**1** may be the distance between centers of the electrodes). The spacing may be based on patient population average distances between target underlying anatomy (e.g., an average distance between the adductor pollicis in the thenar eminence and the distal interphalangeal joint of the thumb) or other suitable distance. By positioning the electrodes at these regions, consistent EMG signals may be obtained.

[0025] Sensing structure **152** is configured to output measurement of electrical activity sensed by electrodes **162** and **164** in response to nerve stimulation and when received at the neuromuscular transmission monitor is recorded as an EMG muscle response signal. Electrodes **162** and **164** are electro-sensors for measuring the action potential of muscle contraction in response to nerve stimulation. Sensing structure **152** includes a lead **166** configured to transmit electrical output from electrodes **162** and **164** to NMT monitor **110**. Lead **166** may be comprised of insulated wires (e.g., copper wire) coupled to flexible substrate **160** at a first end and coupled to a common connector **113** at a second end. The connection between the electrodes and the lead is described in more detail below with respect to FIGS. **6-8**. Connector **113** is configured to couple to NMT monitor **110**, via trunk cable **112** in the illustrated example. Connector **113** is configured to be removeably attached to trunk cable **112**, such that connector **113**, lead **166**, and flexible substrate **160** (with associated electrodes) may be detached from NMT monitor **110** after use. In some examples, connector **113** may couple directly to NMT monitor **110** (e.g., without an intervening cable) or connector **113** may include a communication module or other elements to wirelessly communicate with NMT monitor **110**.

[0026] Stimulating structure **154** includes a flexible substrate **170**, a grounding electrode **172**, and two neurostimulating electrodes **174** and **176** which may apply an electrical stimulus to the patient's ulnar nerve at a pre-determined time interval. Electrodes **174** and **176** may be spaced apart by distance d**2** and electrode **174** and grounding electrode **172** may be spaced apart by distance d**3**. As shown, distance d**2** is smaller than distance d**3**. The distances d**2** and d**3** may be suitable distances of at least 0.5 cm. Flexible substrate **170** may be comprised of similar material as flexible substrate **160** and may be separate from flexible substrate **160**, and thus may allow placement of stimulating structure **154** on a suitable anatomy, regardless of the size of the patient. As shown, the stimulating structure **154** may be placed directly on the wrist of the patient, where the electro-stimulation of the underlying nerve(s) may be strongest and least prone to attenuation by fat or other tissue. Stimulating structure **154** includes a lead **178** coupled to flexible substrate **170** at a first end and to connector **113** at a second end. Lead **178** may be comprised of insulated wires and may be configured to transmit electrical signals to electrodes **174** and **176** in order to stimulate the underlying nerve(s) during NMT monitoring. In this way, stimulating structure **154** may be detachable from MNT monitor **110** after use, along with sensing structure **152**. Connector **113** may only be coupled to leads **166** and **178** (while being configured to couple to cable **112**), and may not be coupled to other leads or inputs. In other examples where the grounding electrode is supported on a separate substrate (e.g., a substrate separate from the flexible substrates **160** and **170**), connector **113** may be coupled to leads **166** and **178** as well as an additional lead coupled to the grounding electrode. In some examples, leads **166** and **178** may be fixedly coupled to connector **113**.

[0027] Stimulating structure **154** and sensing structure **152** may have mechanisms for improving electrical contact to skin, such as conductive gel, and mechanisms for improving fixation to the skin, such as adhesives placed beneath the electrodes. Further, the electrodes may be suitable electrodes, such as silver/silver chloride electrodes. The electrodes may be disposable electrodes which can be discarded after a single use.

[0028] Flexible substrate **160** and flexible substrate **170** are not connected to one another other than the connection of each of the leads to the common connector. Thus, as used herein, the flexible substrates of the sensing structure and of the stimulating structure not being connected to each and/or being maintained separate may include each of the flexible substrates having a border that surrounds and defines each flexible substrate and the borders do not connect or overlap. Thus, a first border of the flexible substrate **160** is maintained continuously around the entirety of the flexible substrate **160**, and a second border of the flexible substrate **170** is maintained continuously around the entirety of the flexible substrate **170**. At least in some examples, the first border and the second border may not touch, overlap, or connect to each other when the NMT sensor is worn by a patient.

[0029] The type of neuromuscular stimulating outputs (e.g., output by stimulating structure **154**) may include

train-of-four (TOF), single twitch (ST), double burst (DBS) and post-tetanic count (PTC). In one example, TOF may typically use four brief (between 100 and 300 μs) current pulses (generally less than 70 mA) at 2 Hz, repeated every 10 to 20 s as electrostimulation. The resulting twitches (i.e. muscle response) may be measured and quantified for electromyographic response via the sensing structure **152**. The first twitch (referred to as the T**1** twitch) and the last twitch (referred to as the T**4** twitch) are compared and the ratio of the last twitch to the first twitch may provide an estimate of the level of neuromuscular blockade (e.g., depth of anesthesia) experienced by the patient. The TOF ratio may range from 0 to 100%, for example. The electrical stimuli series may be spaced by ten or more seconds (generally 20 s is used to provide a margin of safety) to give a rest period for full restoration of steady state conditions, as faster stimulation results in smaller evoked responses. TOF is the most commonly used technique for monitoring the neuromuscular blockade in lightly-blocked patients as well in patients that are recovering from neuromuscular block. However, in deep muscle blockade condition (e.g., during deep sedation), the fourth twitch may be too weak to be detected and thus, may provide a TOF ratio of zero. In that case, the muscle response may be provided at TOF count (TC).

[0030] During NMT monitoring, information regarding the EMG muscle response signals received from sensing structure **152** may be sent to neuromuscular transmission monitor **110** via connector **113** and cable **112**. In one example, muscle response signals from sensing structure **152** may be differentiated and further fed into a signal scaling and filtering circuit (not shown). After scaling the signal and filtering noise, the signal may be converted from an analog signal to a digital signal in analog-to-digital (A/D) converter **122** and sent to microcontroller **123** for processing. Further, the muscle response signals may also be amplified via an amplifier (not shown) before being transmitted into the A/D converter **122**. The microcontroller **123**, or processing unit, is connected to a memory **121** and once the signals are processed, the signal data may be displayed on the display unit **190** of the host patient monitor. In one example, the processed signals may be transmitted to the host patient monitor **140** and displayed on the display unit **190** in real-time. Further still, the processed signals may be updated and stored in memory **121**. Memory **121** may be a conventional microcomputer which includes: a central processing unit (CPU), a read-only memory (ROM), a random access memory (RAM), and a conventional data bus.

[0031] Further still, the microcontroller may be configured to detect errors in the signal received from any of the sensing electrodes. The microcontroller may detect errors such as out-of-range values (e.g., negative values) and alert the user that the electrodes may not be placed properly (e.g., if the electrodes become loose or detached from the skin).

[0032] Control unit **129** may also include a user interface (not shown) which can be used to control operation of the NMT monitoring system **100**, including controlling the input of patient data, changing the monitoring parameters (e.g. stimulus type, current range, frequency/pulse width, etc.), and the like. The user interface may also include a graphical user interface configured for display on a display device, such as display unit **190**. The graphical user interface may include information to be output to a user (such as muscle response signals, patient data, etc.) and may also include menus or other elements through which a user may enter input the control unit **129**.

[0033] Further, CPU **128** may process the input provided by the user and command a constant current source stimulus generator **125** to provide a stimulus waveform and current depending on the selected stimulus mode, current range, and pulse width/frequency. The neurostimulation type may be changed according to the patient's current and overall state of neuromuscular blockade. Further, a conversion module may be provided to convert muscle response value from a non-TOF stimuli into corresponding TOF data. For example, the conversion from PTC to TOF may be mapped using a linear or sigmoidal relationship model, and displayed as a TOF value on the display unit. In another example, the conversion module may further include a duration where a PTC evoked muscle responses may be measureable by TOF stimulation (e.g., if a PTC of 1 is measured, the conversion module may indicate that TOF may be measurable in 12 minutes).

[0034] Thus, the NMT sensor **150** described above provides for a single use, disposable sensor with separate sensing and stimulating parts (comprised of pre-attached electrode bodies that include electrodes coupled to a flexible substrate) intended for monitoring neuromuscular transmission (NMT). The pre-attached electrode bodies each have a supporting shape that may ease the sensor attachment procedure. The electrodes are released faster from the release liner than configurations where each electrode is provided separately, and the correct placement of the electrodes is easier to identify than with separate electrodes. The step where the user connects the correct lead to the specific electrode is eliminated, further easing attachment of the NMT sensor **150** to the patient. By configuring the NMT sensor **150** to be a single use sensor which is disposed after usage, the risk of cross-contamination between patients is minimized and the need for reprocessing of the sensor is eliminated. Further, the two separate flexible substrates provides for easier attachment of the NMT sensor to a patient's hand, which may also contain other medical devices (catheters, etc.) and a wrist band conveying patient identification information, relative to an NMT sensor having only a single body. Also attaching the NMT sensor in two parts makes the handling easier as the adhesive surfaces are less likely to touch unwanted surfaces (instead of skin).

[0035] The shape of sensing structure **152** and/or stimulating structure **154** shown in FIG. **1** is not limiting, as other shapes are possible without departing from the scope of this disclosure. The grounding electrode may be positioned in a suitable location, as long as the grounding electrode is not located directly on the nerve to be stimulated, nor on the same muscles that are measured. The electrodes (e.g., the sensing and/or stimulating electrodes) are positioned a suitable distance apart to prevent the electrodes from coming into electrical contact with each other, even while the patient is moving or is moved by the clinicians. The sufficient isolation between the electrodes may be ensured by having enough distance (>5 mm) between them; or by applying non-conducting material between the electrodes in the electrode element design (such as PE foam). The size of the needed conductive area of each electrode may depend on the used technology. For example, with high-conductive wet gel electrodes sufficient electrical contact (low impedance) with skin may be reached with smaller contact area than with solid gel with smaller amount of chloride ions. The stimu-

lating electrodes may be sized to have some width in relation to the nerve location, to ease the application of the electrodes on the top of the nerve (e.g., make the nerve easier to stimulate). However, the conductive areas of the sensing electrodes may be sized to be smaller than the measured muscle, and the stimulating electrodes may be sized to be smaller than a given width (e.g., 5 cm), as the simultaneous stimulation of the adjacent nerves is to be avoided.

[0036] NMT sensor **150** is configured (e.g., shaped) to sense neuromuscular transmission at a hand of a patient. While such a configuration provides reliable and accurate NMT monitoring, in some circumstance (e.g., where a hand is not available), it may be desirable to monitor NMT on a different anatomy, such as a foot or face of a patient. FIG. **2** shows an embodiment of an NMT sensor **250** configured to be placed on a foot of a patient. NMT sensor **250** includes a sensing structure **252** and a stimulating structure **254**. Sensing structure **252** includes a flexible substrate **260** to which a sensing element is coupled. In the example depicted in FIG. **2**, the sensing element includes two electrodes, a first electrode **262** and a second electrode **264**. Flexible substrate **260** may be similar to flexible substrate **160** (e.g., comprised of PET or other flexible material). Flexible substrate **260** may be shaped to conform to the underlying anatomy (e.g., foot) and thus include a first region configured to be placed on a suitable region of the foot, such as the arch of the foot, for example, and a second region configured to be placed on a suitable region of the foot, such as at the base of the big toe, for example, with a connecting region coupling the first and second regions. The connecting region may be shaped to allow movement of the toes relative to the rest of the foot (e.g., the connecting region may be contoured to match the contour of the foot) and may bend to accommodate differences in patient size, anatomy, and movement. First electrode **262** may be positioned on the first region and second electrode **264** may be positioned on the second region. By positioning the electrodes at these regions, consistent EMG signals may be obtained.

[0037] Sensing structure **252** is configured to output measurement of electrical activity sensed by electrodes **262** and **264** in response to nerve stimulation and when received at the neuromuscular transmission monitor is recorded as an EMG muscle response signal. Electrodes **262** and **264** are electro-sensors for measuring the action potential of muscle contraction in response to nerve stimulation. Electrodes **262** and **264** are spaced apart on the flexible substrate by a distance d**4**. In one example, distance d**4** may be larger than distance d**1** and may be based on the separation of the target underlying anatomy (e.g., the regions of the muscle expected to respond to the stimulation). Sensing structure **252** includes a lead **266** configured to transmit electrical output from electrodes **262** and **264** to an NMT monitor, such as NMT monitor **110**. Lead **266** may be comprised of insulated wires (e.g., copper wire) coupled to flexible substrate **260** at a first end and coupled to a common connector **213** at a second end. The connection between the electrodes and the lead is described in more detail below with respect to FIGS. **6-8**. Connector **213** is configured to couple to a trunk cable, such as cable **112**, that is coupled to the NMT monitor. Connector **213** is configured to be removeably attached to the trunk cable, such that connector **213**, lead **266**, and flexible substrate **260** (with associated electrodes) may be detached from the NMT monitor after use.

[0038] Stimulating structure **254** includes a flexible substrate **270**, a grounding electrode **272**, and two neurostimulating electrodes **274** and **276** which may apply an electrical stimulus to the patient's nerve at a pre-determined time interval. Flexible substrate **270** may be separate from flexible substrate **260**, and thus may allow placement of stimulation structure **254** on a suitable anatomy, regardless of the size of the patient. As shown, the stimulating structure **254** may be placed directly on the ankle of the patient, where the electro-stimulation of the underlying nerve(s) may be strongest and least prone to attenuation by fat or other tissue. Stimulating structure **254** includes a lead **278** coupled to flexible substrate **270** at a first end and to connector **213** at a second end. Lead **278** may be comprised of insulated wires and may be configured to transmit electrical signals to electrodes **274** and **276** in order to stimulate the underlying nerve(s) during NMT monitoring. In this way, stimulating structure **254** may be detachable from the NMT monitor after use, along with sensing structure **252**.

[0039] Stimulating structure **254** and sensing structure **252** may have mechanisms for improving electrical contact to skin, such as conductive gel, and mechanisms for improving fixation to the skin, such as adhesives placed beneath the electrodes. Further, the electrodes may be suitable electrodes, such as silver/silver chloride electrodes. Further, the electrodes may be disposable electrodes which can be discarded after a single use. While FIGS. **1** and **2** show NMT sensors shaped to be placed on a hand and foot, respectively, it is to be understood that an NMT sensor as described herein may be placed in other locations, such as a face of a patient.

[0040] FIG. **3** illustrates an embodiment of an NMT sensor **350** that includes both electro-sensors and mechano-sensors. NMT sensor **350** includes a sensing structure **352** and a stimulating structure **354**. Sensing structure **352** includes a flexible substrate **360** to which sensing elements are coupled. In the example depicted in FIG. **3**, the sensing elements include two electrodes, a first electrode **362** and a second electrode **364**, as well as a mechano-sensor **380**. Flexible substrate **360** may be comprised of silicon, PET, PE, or other material and may be shaped similarly to flexible substrate **160**, and hence description of flexible substrate **160** likewise applies to flexible substrate **360**.

[0041] Sensing structure **352** is configured to output measurement of electrical activity sensed by electrodes **362** and **364** in response to nerve stimulation and when received at the neuromuscular transmission monitor is recorded as an EMG muscle response signal. Electrodes **362** and **364** are electro-sensors for measuring the action potential of muscle contraction in response to nerve stimulation.

[0042] Mechano-sensor **380** is configured for measuring muscle movement in response to nerve stimulation. Mechano-sensor **380** includes a mechano-sensing bending element. In the depicted example, the bending element is placed between the thumb and the forefinger. The bending element may comprise a piezoelectric polymer film which creates an electrical current in response to movement of any part of the polymer. When compressed or distorted, piezoelectric materials produce a charge proportional to the degree of alteration in shape. In FIG. **3**, when the motor nerve is stimulated, thumb movement may cause a shape distortion in the bending element which in turn produces an electrical signal transmitted to an NMT monitor and recorded at the monitor as a KMG muscle response signal. Mechano-sensor **380** may be coupled to a top layer of

flexible substrate **360**, such that underlying electrodes **362** and/or **364** are in contact with the skin of the patient. In some examples, mechano-sensor **380** may be sandwiched intermediate two layers of the flexible substrate.

[0043] Sensing structure **352** includes a lead **366** configured to transmit electrical output from electrodes **162** and **164** and mechano-sensor **380** to an NMT monitor, such as NMT monitor **110**. Lead **366** may be comprised of insulated wires (e.g., copper wire) coupled to flexible substrate **360** at a first end and coupled to a common connector **313** at a second end. The connection between the electrodes and the lead is described in more detail below with respect to FIGS. **6-8**. Connector **313** is a non-limiting example of connector **113** and thus description of connector **113** likewise applies to connector **313**. By including both EMG sensors and a KMG sensor, NMT sensor **350** may be configured to output both EMG and KMG muscle response signals. The NMT monitor may use both the EMG and KMG muscle response signals to monitor NMT, thereby allowing for filtering of noise from the electrical EMG signal based on the mechanical KMG signal, increasing robustness in the monitoring, and providing back-up/redundant sensing.

[0044] Stimulating structure **354** includes a flexible substrate **370**, a grounding electrode **372**, two neurostimulating electrodes **374** and **376** which may apply an electrical stimulus to the patient's ulnar nerve at a pre-determined time interval, and a lead **378**. Stimulating structure **354** is a non-limiting example of stimulating structure **154** and thus description of stimulating structure **154** and all components comprising stimulating structure **154** likewise applies to stimulation structure **354**.

[0045] FIG. **4** shows an embodiment of an NMT sensor **450** including a mechanical (e.g., movement) sensor in the form of an accelerometer. NMT sensor **450** includes a sensing structure **452** and a stimulating structure **454**. Sensing structure **452** includes a flexible substrate **460** to which sensing elements are coupled. In the example depicted in FIG. **4**, the sensing elements include two electrodes, a first electrode **462** and a second electrode **464**, as well as accelerometer **480**. Flexible substrate **460**, electrodes **462** and **464**, and lead **466** are non-limiting examples of flexible substrate **160**, electrodes **162** and **164**, and lead **166** and hence description of flexible substrate **160**, electrodes **162** and **164**, and lead **166** likewise apply to flexible substrate **360**, electrodes **462** and **464**, and lead **466**. Accelerometer **480** is configured to measure movement (e.g., acceleration) of the thumb (or other underlying anatomy) that occurs responsive to electric stimulation. Accelerometer **480** may be a suitable accelerometer, such as a piezoelectric, piezoresistive, capacitive, or MEMS accelerometer. In FIG. **4**, when the motor nerve is stimulated, thumb movement may cause accelerometer **480** to produce an electrical signal that is transmitted to an NMT monitor and recorded at the monitor as a KMG muscle response signal. Accelerometer **480** may be coupled to a top layer of flexible substrate **460**, such that underlying electrode **462** is in contact with the skin of the patient. In some examples, accelerometer **480** may be sandwiched intermediate two layers of the flexible substrate.

[0046] Stimulating structure **454** includes a flexible substrate **470**, a grounding electrode **472**, two neurostimulating electrodes **474** and **476** which may apply an electrical stimulus to the patient's ulnar nerve at a pre-determined time interval, and a lead **478**. Stimulation structure **454** is a non-limiting example of stimulation structure **154** and thus description of stimulation structure **154** and all components comprising stimulation structure **154** likewise applies to stimulation structure **454**. Connector **413** is a non-limiting example of connector **113** and thus description of connector **113** likewise applies to connector **413**. Further, while the NMT sensor **450** is configured for placement on a hand of a patient, in some examples a similar NMT sensor (e.g., that includes a sensing structure having two electrodes and an accelerometer) may be configured for placement on a foot or other anatomy of a patient.

[0047] FIG. **5** shows an embodiment of an NMT sensor **550** configured to measure EMG signals at a hand of a patient. NMT sensor **550** includes similar components as NMT sensor **150**. However, in NMT sensor **550**, the grounding electrode is positioned on the same flexible substrate as the sensing electrodes rather than on the flexible substrate of the stimulating structure. Thus, NMT sensor **550** includes a sensing structure **552** and a stimulating structure **554**. Sensing structure **552** includes a flexible substrate **560** to which sensing elements are coupled. In the example depicted in FIG. **5**, the sensing elements include two electrodes, a first electrode **562** and a second electrode **564**. Flexible substrate **560**, electrodes **562** and **564**, and lead **566** are non-limiting examples of flexible substrate **160**, electrodes **162** and **164**, and lead **166** and hence description of flexible substrate **160**, electrodes **162** and **164**, and lead **166** likewise apply to flexible substrate **560**, electrodes **562** and **564**, and lead **566**. Sensing structure **552** further includes a grounding electrode **580**, which may be placed at a centerline over the flexor retinaculum at the palmar side of the wrist or other suitable location. To accommodate the grounding electrode **580**, flexible substrate **560** may be longer and/or wider than flexible substrate **160**, at least in the region where the grounding electrode is positioned. Electrodes **562** and **564** may be spaced apart by distance d**5**, which may be the same distance as d**1** described above with respect to FIG. **1**. Electrode **564** and grounding electrode **580** may be spaced apart by a distance d**6**, which may be smaller than d**5** and may have a minimum distance of 0.5 cm. Electrodes **562** and **564** may be positioned on-axis with each other, and electrode **564** and grounding electrode **580** may also be positioned on-axis with each other along an axis that is perpendicular to the axis along which electrodes **562** and **564** are aligned. Thus, electrode **562** and grounding electrode **580** may be aligned along an axis that is angled relative to the axis along which electrode **564** and grounding electrode **580** are aligned, such as angle of 45° or 60°.

[0048] Stimulating structure **554** includes a flexible substrate **570**, two neurostimulating electrodes **574** and **576** which may apply an electrical stimulus to the patient's ulnar nerve at a pre-determined time interval, and a lead **578**. Stimulating structure **554** is a non-limiting example of stimulating structure **154** and thus description of stimulating structure **154** and the components comprising stimulating structure **154** likewise applies to stimulating structure **554**. In some examples, flexible substrate **570** may be shorter and/or narrower than flexible substrate **170** due to the lack of a grounding electrode on flexible substrate **570**. Connector **513** is a non-limiting example of connector **113** and thus description of connector **113** likewise applies to connector **513**.

[0049] FIG. **6** schematically illustrates a top-down view of an example configuration for a stimulating structure **600** including a flexible substrate housing a plurality of elec-

trodes. Simulating structure is a non-limiting example of stimulating structures **154**, **254**, **354**, **454**, and **554**. While FIG. **6** is described with respect to a stimulating structure, the configuration described below likewise may be applied to a sensing structure. Stimulating structure **600** includes a first layer comprising a flexible substrate **602**. Flexible substrate **602** may be comprised of silicon, polyethylene terephthalate (PET), PE, or other suitable flexible, non-conductive material. Flexible substrate **602** may be comprised of a single layer of material, or it may be comprised of more than one layer of material glued or otherwise coupled together. Flexible substrate **602** may be comprised of a continuous layer (or layers) of material (other than including cut-outs or openings to accommodate electrodes where appropriate), or flexible substrate **602** may be comprised of multiple segments of material joined together. A second layer of stimulating structure **600** includes a layer of adhesive foam **604**. A plurality of electrodes may be coupled to flexible substrate **602** and/or adhesive foam **604**, including a first electrode **606**, a second electrode **608**, and a third electrode **610** (in some examples, third electrode **610** may be omitted from stimulating structure **600**). In some examples, the layer of adhesive foam **604** may include openings to accommodate each electrode, and each electrode may be directly coupled to the flexible substrate **602**. In other examples, each electrode may be directly coupled to the layer of adhesive foam. In either example, front faces of the electrodes are not covered by the adhesive foam such that the electrodes are capable of making electrical contact with the skin of a patient.

[0050] Each electrode may be surrounded by a cushion of conductive gel in a sponge, including cushion **612**, cushion **614**, and cushion **616**. The cushions of conductive gel may enhance electrical coupling between the electrodes and skin of the patient. The cushions may be coupled directly to the flexible substrate or to the layer of adhesive foam. While not shown in FIG. **6**, in some examples, the conductive gel sponges may be coupled across the front faces of the electrodes, such that the electrodes electrically contact the skin of the patient via the conductive gel.

[0051] Each electrode is coupled to a lead. As shown, electrode **606** is coupled to lead **618**, electrode **608** is coupled to lead **620**, and electrode **610** is coupled to lead **622**. Each lead may be comprised of conductive ink that is printed, painted, or otherwise applied to flexible substrate **602**. As such, the leads may be sandwiched intermediate flexible substrate **602** and the layer of adhesive foam **604**. The conductive ink may include carbon, silver, or other conductive particles suspended in ink. Each of the leads may be joined to form a collective lead **624** that couples stimulating structure **600** to a connector (such as connector **113**). Collective lead **624** may include each of lead **618**, lead **620**, and lead **622** coupled to and/or encapsulated by a non-conductive material, such as non-conductive paint, rubber, or other material.

[0052] While not shown in FIG. **6**, a sensing structure may be configured in a similar manner, including electrodes coupled to a flexible substrate and with leads comprised of conductive ink printed on the flexible substrate. In examples where a piezoelectric mechano-sensor or accelerometer is included in addition (or alternative) to the electrodes, the mechano-sensor or accelerometer may be coupled to the flexible substrate (e.g., on the opposite side as the electrodes) and may be coupled to a lead comprised of conductive ink.

[0053] Rather than including printed leads, some stimulating or sensing structures may include lead wires. FIGS. **7** and **8** show example configurations for sensing or stimulating structures comprising lead wires. FIG. **7** schematically illustrates a cross-sectional view of an example configuration for a stimulating structure **700** including a flexible substrate housing a plurality of electrodes. Stimulating structure **700** is a non-limiting example of stimulating structure **154**, **254**, **354**, **454**, and **554**. While FIG. **7** is described with respect to a stimulating structure, the configuration described below likewise may be applied to a sensing structure. Stimulating structure **700** includes a first layer comprising a flexible substrate **702**. Flexible substrate may be comprised of silicon, polyethylene terephthalate (PET), PE, or other suitable flexible, non-conductive material. Flexible substrate **702** may be comprised of a single layer of material, or it may be comprised of more than one layer of material glued or otherwise coupled together. Flexible substrate **702** may be comprised of a continuous layer (or layers) of material (other than including cut-outs or openings to accommodate electrodes where appropriate), or flexible substrate **702** may be comprised of multiple segments of material joined together. A second layer of stimulating structure **700** includes a layer of adhesive foam **704**. A plurality of electrodes may be coupled to flexible substrate **702**, including a first electrode **706**, a second electrode **708**, and an optional third electrode **710**. In some examples, the layer of adhesive foam **704** may include openings to accommodate each electrode, and each electrode may be directly coupled to the flexible substrate **702**.

[0054] Each electrode may be surrounded by a cushion of conductive gel in a sponge, including cushion **712**, cushion **714**, and cushion **716**. The cushions of conductive gel may enhance electrical coupling between the electrodes and skin of the patient. The cushions may be coupled directly to the flexible substrate and/or to the layer of adhesive foam. As shown in FIG. **7**, the conductive gel sponges may be coupled across the front faces of the electrodes, such that the electrodes electrically contact the skin of the patient via the conductive gel.

[0055] Each electrode is coupled to a lead. As shown, electrode **706** is coupled to lead **718**, electrode **708** is coupled to lead **720**, and electrode **710** is coupled to lead **722**. Each lead may be comprised of conductive wire or wires, such as copper wire. Each of the leads may be bundled to form a collective lead **724** that couples stimulating structure **700** to a connector (such as connector **113**). Collective lead **724** may include each of lead **718**, lead **720**, and lead **722** coupled to/encapsulated in a non-conductive material, such as rubber or other material. A layer of insulating material **728** may be coupled to flexible substrate **702**, on an opposite of the electrodes, and may surround and/or encapsulate the conductive wire leads.

[0056] While not shown in FIG. **7**, a sensing structure may be configured in a similar manner, including electrodes coupled to a flexible substrate and with leads comprised of conductive wire. In examples where a piezoelectric mechano-sensor or accelerometer is included in addition (or alternative) to the electrodes, the mechano-sensor or accelerometer may be coupled to the flexible substrate (e.g., on

the opposite side as the electrodes) and may be coupled to a lead comprised of conductive wire.

[0057] FIG. **8** schematically illustrates a cross-sectional view of an example configuration for a stimulating structure **800** including a flexible substrate housing a plurality of electrodes. Stimulating structure **800** is a non-limiting example of stimulating structure **154**, **254**, **354**, **454**, and **554**. While FIG. **8** is described with respect to a stimulating structure, the configuration described below likewise may be applied to a sensing structure. Stimulating structure **800** includes a first layer comprising a flexible substrate **802**. Flexible substrate may be comprised of silicon, polyethylene terephthalate (PET), PE, or other suitable flexible, non-conductive material. Flexible substrate **802** may be comprised of a single layer of material, or it may be comprised of more than one layer of material glued or otherwise coupled together. Flexible substrate **802** may be comprised of a continuous layer (or layers) of material (other than including cut-outs or openings to accommodate electrodes where appropriate), or flexible substrate **802** may be comprised of multiple segments of material joined together. A plurality of electrodes may be coupled to flexible substrate **802**, including a first electrode **806**, a second electrode **808**, and an optional third electrode **810**.

[0058] Each electrode may be surrounded by a layer of adhesive conductive solid gel, including layer **812**, layer **814**, and layer **816**. The layers of conductive gel may enhance electrical coupling between the electrodes and skin of the patient and maintain the structure coupled to the skin of the patient. The layers may be coupled directly to the flexible substrate. As shown in FIG. **8**, the conductive gel layers may be coupled across the front faces of the electrodes, such that the electrodes electrically contact the skin of the patient via the conductive gel. The conductive solid gel is a relatively stable conductor, in that it may be less likely to run or exude from the electrode area than the conductive wet gel in the sponge described above, and may have a longer shelf life than the conductive wet gel. However, the conductive wet gel in the sponge may be a more effective conductor which quickly moisturizes the dry top surface of the skin (Stratum Corneum) and thus a good, low impedance electrical contact is reached in short time.

[0059] Each electrode is coupled to a lead. As shown, electrode **806** is coupled to lead **818**, electrode **808** is coupled to lead **820**, and electrode **810** is coupled to lead **822**. Each lead may be comprised of conductive wire or wires, such as copper wire. Each of the leads may be bundled to form a collective lead **824** that couples stimulating structure **800** to a connector (such as connector **113**). Collective lead **824** may include each of lead **818**, lead **820**, and lead **822** coupled to/encapsulated in a non-conductive material, such as rubber or other material. A layer of insulating material **828** may be coupled to flexible substrate **802**, on an opposite of the electrodes, and may surround and/or encapsulate the conductive wire leads.

[0060] While not shown in FIG. **8**, a sensing structure may be configured in a similar manner, including electrodes coupled to a flexible substrate and with leads comprised of conductive wire. In examples where a piezoelectric mechano-sensor or accelerometer is included in addition (or alternative) to the electrodes, the mechano-sensor or accelerometer may be coupled to the flexible substrate (e.g., on the opposite side as the electrodes) and may be coupled to a lead comprised of conductive wire. For example, FIG. **8** shows an accelerometer **830** coupled to flexible substrate **802**, opposite the electrodes. Accelerometer **830** is coupled to a lead **832** (e.g., comprised of conductive wire), and lead **832** may be bundled with the other leads at the overall lead **824**.

[0061] In some examples, a plurality of NMT sensors may be packaged together in a kit. FIG. **9** shows an example kit **900** including a plurality of NMT sensors **902**. The plurality of NMT sensors **902** includes a first NMT sensor **950**. NMT sensor **950** is a non-limiting example of NMT sensor **150** and thus may include the components of NMT sensor **150** described above with respect to FIG. **1**, including a sensing structure **952**, stimulating structure **954**, leads **966** and **978**, and a connector **913**. The other NMT sensors of the plurality of NMT sensor **902** may be configured similarly to NMT sensor **950**. The plurality of NMT sensors **902** may be packaged in a suitable packaging **904**, such as a box.

[0062] The technical effect of an NMT sensor comprising a first flexible substrate with muscle response sensing element(s) attached thereon and a second flexible substrate with stimulating electrodes attached thereon is adaptivity to a desired anatomical monitoring site, enhanced ergonomics (including elimination of folded parts when attached to a patient of relatively small size, such as a child), and reduced pulling forces on the cables.

[0063] As used herein, an element or step recited in the singular and proceeded with the word "a" or "an" should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to "one embodiment" of the present invention are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising," "including," or "having" an element or a plurality of elements having a particular property may include additional such elements not having that property. The terms "including" and "in which" are used as the plain-language equivalents of the respective terms "comprising" and "wherein." Moreover, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements or a particular positional order on their objects.

[0064] This written description uses examples to disclose the invention, including the best mode, and also to enable a person of ordinary skill in the relevant art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

1. A sensor for monitoring neuromuscular transmission (NMT) of a patient, comprising:

a first flexible substrate including a sensing element for measuring patient response to a stimulus;

a second flexible substrate for providing the stimulus to the patient, the second flexible substrate including at least two electrodes, the first flexible substrate not connected to the second flexible substrate; and

a common connector coupled to both the first flexible substrate and the second flexible substrate, the connector configured to couple to an NMT monitoring device.

2. The sensor of claim **1**, wherein the sensing element comprises at least two electrodes for measuring electrical activation of a muscle of the patient.

3. The sensor of claim **1**, wherein the sensing element comprises a mechanical sensor for measuring mechanical activation of a muscle of the patient.

4. The sensor of claim **3**, wherein the mechanical sensor comprises a piezoelectric bending element or an accelerometer.

5. The sensor of claim **1**, further comprising a first flexible lead coupled to the first flexible substrate and to the connector and a second flexible lead coupled to the second flexible substrate and to the connector.

6. The sensor of claim **5**, wherein the first flexible lead is configured to electrically couple the sensing element to the connector and the second flexible lead is configured to electrically couple the at least two electrodes to the connector.

7. The sensor of claim **6**, wherein the first flexible lead and the second flexible lead each comprises one or more conductive wires encapsulated in a non-conductive material.

8. The sensor of claim **6**, wherein the first flexible lead and the second flexible lead each comprises one or more strips of conductive ink printed on a non-conductive material.

9. The sensor of claim **1**, wherein the sensing element comprises at least two electrodes for measuring electrical activation of a muscle of the patient and a piezoelectric bending element for measuring mechanical activation of the muscle of the patient.

10. The sensor of claim **1**, wherein the sensing element comprises at least two electrodes for measuring electrical activation of a muscle of the patient and an accelerometer for measuring mechanical activation of the muscle of the patient.

11. The sensor of claim **1**, wherein the first flexible substrate is shaped to conform to a hand of the patient.

12. The sensor of claim **1**, wherein the first flexible substrate is shaped to conform to a foot of the patient.

13. The sensor of claim **1**, wherein the first flexible substrate comprises a single, continuous layer of non-conductive material, and the second flexible substrate comprises a single, continuous layer of non-conductive material.

14. A sensor for monitoring neuromuscular transmission (NMT), comprising:

a first flexible substrate supporting at least two first electrodes for measuring muscle electrical response to a stimulus and a mechanical sensor for measuring muscle mechanical response to the stimulus;

a second flexible substrate supporting at least two second electrodes for providing the stimulus, the second flexible substrate not connected to the first flexible substrate; and

a common connector coupled to both the first flexible substrate and the second flexible substrate, the connector configured to couple to an NMT monitoring device.

15. The sensor of claim **14**, wherein the at least two first electrodes are coupled to a first side of the first flexible substrate and the mechanical sensor is coupled to a second, opposite side of the first flexible substrate.

16. The sensor of claim **14**, wherein the mechanical sensor comprises a piezoelectric bending element or an accelerometer.

17. The sensor of claim **14**, further comprising a grounding electrode supported on the first flexible substrate or second flexible substrate.

18. A kit, comprising:

a plurality of neuromuscular transmission (NMT) sensors packaged in a common packaging, each NMT sensor of the plurality of NMT sensors comprising:

a first flexible substrate supporting a sensing element for measuring patient response to a stimulus and coupled to a first lead;

a second flexible substrate supporting at least two electrodes for providing the stimulus and coupled to a second lead, the second flexible substrate not connected to the first flexible substrate; and

a common connector coupled to both the first lead and the second lead, the connector configured to couple to an NMT monitoring device.

19. The kit of claim **18**, wherein each sensing element comprises at least two electrodes.

20. The kit of claim **18**, wherein the first lead and the second lead each comprise a plurality of conductive wires encapsulated in a flexible insulating material.

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专利名称(译)	用于神经肌肉传输测量的一次性传感器		
公开(公告)号	US20190192051A1	公开(公告)日	2019-06-27
申请号	US15/853610	申请日	2017-12-22
[标]申请(专利权)人(译)	通用电气公司		
申请(专利权)人(译)	通用电气公司		
当前申请(专利权)人(译)	通用电气公司		
[标]发明人	SAVINEN OUTI KRISTIINA		
发明人	SAVINEN, OUTI KRISTIINA		
IPC分类号	A61B5/11 A61B5/0492 A61B5/00		
CPC分类号	A61B5/1106 A61B5/0492 A61B5/6825 A61B5/6829 A61B2562/0219 A61B2562/164 A61B5/0022 A61B5/486 A61B5/746 A61B2505/05 A61B2560/0214 G16H40/67		
外部链接	Espacenet USPTO		

摘要(译)

提供传感器用于监测患者的神经肌肉阻滞。在一个实施例中，传感器包括第一柔性基板，其包括用于测量患者对刺激的响应的感测元件，用于提供刺激的第二柔性基板，第二柔性基板包括至少两个电极，第一柔性基板未连接到第二柔性基板和连接到第一柔性基板和第二柔性基板的公共连接器，该连接器被配置为耦合到NMT监控设备。