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Integrated probe structure

Abstract

According to various embodiments, there is provided a probe structure. The probe structure includes a probe configured to emit acoustic energy. The probe structure further includes a load cell underneath and aligned with the probe. The probe structure further includes a probe hub including a cavity for receiving the probe and the load cell.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. application Ser. No. 16/847,247, filed Apr. 13, 2020, now U.S. Pat. No. 11,452,500, granted Sep. 27, 2022, which is a continuation of U.S. application Ser. No. 15/399,440, filed Jan. 5, 2017, now U.S. Pat. No. 10,617,388, granted Apr. 14, 2020, which claims the benefit of and priority to U.S. Provisional Application No. 62/332,133, filed May 5, 2016, and U.S. Provisional Application No. 62/275,192, filed Jan. 5, 2016, the contents of which are incorporated herein by reference in their entireties.

BACKGROUND
1. Field
(1) Subject matter described herein relates generally to medical devices, and more particularly to a

probe for diagnosing medical conditions.

2. Background

(2) For devices utilizing a probe (e.g., an automated Transcranial Doppler (TCD) device), there exist patient safety concerns related to the placement and alignment of TCD probes against a human being's skull. This safety concern exists within the structure of an automated robotic headset or manual operation of TCD probes. In existing solutions, either manual placement of the TCD probe or the complexity of the TCD probe mechanism may not be optimal. Currently there is no method to observe the amount of pressure or force exerted on a patient's temporal window or skull and thus there are no mediums to monitor patient discomfort during an automated or manual TCD probe placement.

SUMMARY

(3) In general, various embodiments relate to systems and methods for providing an integrated probe structure incorporating a probe integrated with a gimbal structure or probe hub.

(4) According to various embodiments, there is provided a probe structure. The probe structure includes a probe configured to emit acoustic energy. The probe structure further includes a load cell underneath and aligned with the probe. The probe structure further includes a probe hub including a cavity for receiving the probe and the load cell.

(5) In some embodiments, the probe structure further includes a probe seat interposed between the probe and the load cell.

(6) In some embodiments, the probe hub includes a lengthwise slot.

(7) In some embodiments, the lengthwise slot is configured to align and retain a cable connected to the probe and a wire connected to the load cell.

(8) In some embodiments, the wire connected to the load cell is held statically within the lengthwise slot while the cable of the probe is configured to move along the lengthwise slot.

(9) In some embodiments, the probe structure further includes an adhesive layer between the load cell and a bottom of the cavity of the probe hub.

(10) In some embodiments, the load cell further includes a probe seat interposed between the probe and the load cell and an adhesive layer between the probe and the probe seat.

(11) In some embodiments, the adhesive layer includes epoxy.

(12) In some embodiments, the load cell includes a protrusion and the probe includes a hollow for receiving the protrusion for securing the load cell and the probe together.

(13) In some embodiments, the probe structure further includes a probe seat interposed between the probe and the load cell, wherein the probe seat has a through hole such that the protrusion of the load cell threads through the through hole and the hollow of the probe.

(14) In some embodiments, the probe hub is configured to house the load cell and a portion of the probe.

(15) In some embodiments, the cavity of the probe hub includes an inner diameter that is substantially equal to an outer diameter of the portion of the probe.

(16) In some embodiments, the cavity of the probe hub includes a first inner diameter corresponding to a location of the portion of the probe housed within the cavity and a second inner diameter corresponding to a location of the load cell housed within the cavity, the first inner diameter being different from the second inner diameter.

(17) In some embodiments, the first inner diameter is greater than the second inner diameter.

(18) In some embodiments, the first inner diameter is substantially equal to an outer diameter of the portion of the probe and the second inner diameter is substantially equal to an outer diameter of the load cell.

(19) In some embodiments, the probe structure further includes a probe seat interposed between the probe and the load cell, wherein the first inner diameter further corresponds to a location of the probe seat housed within the cavity.

(20) In some embodiments, the load cell is configured to detect forces exerted against the probe

along a plurality of axes.
(21) In some embodiments, the probe includes a transcranial Doppler (TCD) probe.
(22) According to various embodiments, there is provided a method of manufacturing a probe structure. The method includes providing a probe configured to emit acoustic energy. The method further includes aligning a load cell underneath the probe. The method further includes providing a probe hub including a cavity for receiving the probe and the load cell.
(23) According to various embodiments, there is provided a system for detecting neurological conditions of a subject. The system includes automated robotics configured to position a probe structure with respect to the subject. The probe structure includes a probe configured to emit acoustic energy. The probe structure further includes a load cell underneath and aligned with the probe. The probe structure further includes a probe hub including a cavity for receiving the probe and the load cell.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** illustrates a perspective view of a TCD probe previously known in the art.
(2) FIG. **2** illustrates a robotic headset for incorporating a TCD probe.
(3) FIG. **3** illustrates a perspective view of an integrated TCD probe structure according to various embodiments.
(4) FIG. **4** is an exploded view of an integrated TCD probe structure according to various embodiments.
(5) FIG. **5** illustrates a side cross-sectional view of an integrated TCD probe structure according to various embodiments.
(6) FIG. **6** illustrates a perspective view of an integrated gimbal probe structure according to various embodiments.
(7) FIG. **7** illustrates a side view of an integrated gimbal probe structure according to various embodiments.
(8) FIG. **8** illustrates a perspective view of a TCD probe adapted for use with an integrated gimbal probe structure with a cover according to various embodiments.
(9) FIG. **9** illustrates a perspective view of an integrated force center probe according to various embodiments.
(10) FIG. **10** illustrates a side cross-sectional view of a TCD probe adapted for use with a three piece integrated gimbal probe structure according to various embodiments.
(11) FIG. **11** illustrates a perspective exploded view of a TCD probe adapted for use with an integrated gimbal probe structure integrated with a cover according to various embodiments.
(12) FIG. **12**A illustrates a perspective view of an integrated probe structure according to various embodiments.
(13) FIG. **12**B illustrates an exploded view of the integrated probe structure shown in FIG. **12**A according to various embodiments.
(14) FIG. **12**C illustrates a perspective cross-sectional view of the integrated probe structure shown in FIG. **12**A according to various embodiments.
(15) FIG. **13**A illustrates a perspective view of an integrated probe structure according to various embodiments.
(16) FIG. **13**B illustrates a transparent perspective view of the integrated probe structure shown in FIG. **13**A according to various embodiments.
(17) FIG. **13**C illustrates an exploded view of the integrated probe structure shown in FIG. **13**A according to various embodiments.
DETAILED DESCRIPTION

(18) The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

(19) FIG. **1** illustrates a side view of a prior art TCD probe **102** pressed against a human being's skull **104**. In the prior art, when a TCD probe **102** was manipulated by a human operator (e.g., a skilled sonographer operating a TCD probe), it was not critical to reduce the size of the TCD probe **102**.

(20) FIG. **2** illustrates a robotic headset **106** mounted on a human being's skull **104**. To facilitate automated TCD scans without the use of a human operator manipulating a TCD probe, it would be advantageous to reduce the size of a TCD probe so that it would fit within a reasonably sized headset **106**.

(21) FIG. **3** illustrates a perspective view of a TCD probe **202** mounted in a gimbal **204** for use in a robotic headset **106**. While this specification frequently discusses TCD probes, in general, the techniques and devices discussed herein specifically described as using TCD can also be employed in various embodiments using probes for methods such as ultrasound, transcranial color-coded sonography (TCCS), phased arrays, as well as other known ultrasound energy modalities. Additionally, other techniques that use probes that emit or receive energy in the electromagnetic spectrum such as functional Near-Infrared Spectroscopy (fNIRS) or EEG can also be employed. In some embodiments, the gimbal **204** includes a pivoted support that allows for rotation of an object (e.g., the probe **202**), about an axis (e.g., about a single axis). In some embodiments, the gimbal **204** is a probe hub. Further disclosure regarding the probe hub is described below. A data/power cable **206** allows for the flow of electricity to power the TCD probe **202** and the flow of data from the TCD probe **202**. The gimbal **204** allows the TCD probe **202** to pan and tilt.

(22) FIG. **4** illustrates an exploded view of the TCD probe **202** connection to the gimbal **204**. To allow for connection of the TCD probe **202** to the gimbal **204**, the TCD probe **202** is fastened, typically with glue, to a thrust plate **208**. The thrust plate **208** has a plurality of legs **210***a*, **210***b*, **210***c*, **210***d* designed to mount in and align with corresponding receiving holes **212***a*, **212***b* (other holes **212***c*, **212***d* not shown). The thrust plate **208** is secured to the gimbal **204** by snap rings (not shown) on the bottom of the gimbal **204**. Other methods of fastening known to those of skill in the art may also be employed, such as, but not limited to, interfacing (e.g., counter sunk features). A load cell **214** is fastened, typically with a form to fit counter sunk feature for initial alignment and with glue for stabilization, to the gimbal **204**, and is designed to fit between the gimbal **204** and thrust plate **208**. As is known in the art, a load cell **214** is a transducer that is used to translate physical phenomenon into an electrical signal whose magnitude is proportional to, in this case, the force being measured. Wires **216** extending from the load cell **214** provide electrical signals (e.g., data and power signals) emanating from the load cell **214** responsive to the force on the load cell **214**. In operation, when the TCD probe **202** is pressed against a human being's skull **104**, a force will also be imparted through the interfacing thrust plate **208** to the load cell **214**, which will result in an electrical signal which can be measured.

(23) FIG. **5** illustrates a perspective cross-sectional view of the of the TCD probe **202** connected to the thrust plate **208**, which is in turn in contact with the load cell **214** connected to the gimbal **204**.

(24) FIG. **6** illustrates a perspective view of a preferred embodiment of an integrated gimbal TCD probe **300** and FIG. **7** illustrates an elevation view of the integrated gimbal TCD probe **300**. The integrated gimbal TCD probe **300** reduces the number of components compared to the embodiment of FIG. **4**. The integrated gimbal TCD probe **300** has a TCD probe **302** capable of transmitting ultrasound waves into a human being's skull **104**. The ultrasound waves are transmitted through the

transducer face **303** which is pressed against the skin of a human being's skull **104**. The TCD probe **302**, rather than being cylinder shaped, has a tapered portion **304** adapted to receive a cover (as shown in FIG. **8**). Beyond the tapered portion **304**, the TCD probe **302** probe body **306** extends to a gimbal mount **314**. The gimbal mount **314** has a plurality of tapped holes **310***a*, **310***b*, designed to mount with and allow for fastening of the gimbal mount **314** to a gimbal interface. A data/power cable **312** extends from the gimbal mount **314** of the integrated gimbal TCD probe **300** such that it has proper clearance from the gimbal.

(25) FIG. **8** illustrates a TCD probe **402** having a shape similar to the integrated gimbal TCD probe **300** shown in FIG. **6**. The TCD probe **402** has a tapered portion **404** adapted to receive a cover **406**. The cover **406** mounts snugly to the tapered portion **404** to prevent a patient's skin from being pinched between the TCD probe **402** and any other mechanism of the robotic headset **106**. Further, in operation, gel is typically placed on a transducer face **408** of the TCD probe **402** to provide improved conductivity between the skin of the patient and the transducer face **408**. Employing a cover **406** snugly mounted with the tapered portion **404** will act to help prevent gel from moving past the tapered portion into the rest of the mechanism of the robotic headset **106**. If gel were to move into the mechanism of the robotic headset **106**, the gel may degrade operation of the robotic headset **106** or may require that the robotic headset **106** be cleaned from time to time to remove unwanted gel.

(26) FIG. **9** illustrates a perspective view of an integrated force center probe **500**. The integrated force center probe **500** includes a TCD probe **502** capable of transmitting ultrasound waves into a human being's skull **104**. The TCD probe **502** has a tapered portion **504** adapted to receive a cover (as shown in FIG. **8**). Below the tapered portion **504**, the TCD probe **502** probe body **506** extends to a gimbal mount **514**. Between the gimbal mount **514** and the probe body **506**, an overmold piece **516** connects the gimbal mount **514** and the probe body **506**. The gimbal mount **514** has a plurality of tapped holes **510** designed to mount with and allow for fastening of the gimbal mount **514** to a gimbal. A data/power cable **512** extends from the gimbal mount **514** of the integrated gimbal TCD probe **500** such that it has proper clearance from the gimbal.

(27) FIG. **10** illustrates a cross-sectional side view of the integrated force center probe **500**. A load cell **508** is molded into the bottom of TCD probe **502** having a probe body **506**. The assembly of the load cell **508** and TCD probe **502** is then molded to gimbal mount **514** such that when the load cell **508** contacts the gimbal mount **514** a specific pre-defined preload is applied to a button **518** on the load cell **508**. The gimbal mount **514** and probe body **506** are then molded together with an overmold piece **516**. A data/power cable **512** extends from the gimbal mount **514** of the integrated force center probe **500** such that it has proper clearance from the gimbal.

(28) FIG. **11** illustrates a perspective view of an exploded portion of the integrated force center probe **500** oriented in a direction opposite that of FIG. **10**. This view does not show the gimbal mount **514** or the data/power cable **512**. Load cell **508** is mounted within a recess or countersink **520** of the probe body **506**. Wires **522** extending from the load cell **508** provide electrical signals emanating from the load cell **508** responsive to the force on the load cell **508**. The wires **522** exit the probe body **506** through a recess **524** in the probe body **506**.

(29) FIG. **12**A illustrates a perspective view of an integrated probe structure **1200** according to various embodiments. FIG. **12**B illustrates an exploded view of the integrated probe structure **1200** shown in FIG. **12**A according to various embodiments. FIG. **12**C illustrates a perspective cross-sectional view of the integrated probe structure **1200** shown in FIG. **12**A according to various embodiments.

(30) Referring to FIGS. **12**A-**12**C, the probe structure **1200** includes a probe **1202**, a probe hub or gimbal **1204**, a probe seat **1206**, and a load cell **1208**. In some embodiments, the probe **1202** includes a first end (e.g., the end that is free and facing empty space) and a second end that is opposite to the first end. In some embodiments, the first end includes a concave surface that is configured to be adjacent to or contact a scanning surface. The concave surface is configured with

a particular pitch to focus generated energy towards the scanning surface. In some embodiments, the probe structure is a Transcranial Doppler (TCD) apparatus such that the first end of the probe is configured to be adjacent to or contact and align along a human head (e.g., a side of the human head), and the first end of the probe **1202** is configured to provide ultrasound wave emissions from the first end and directed into the human head (e.g., towards the brain). In other embodiments, the probe **1202** is configured to emit other types of waves during operation, such as, but not limited to, infrared waves, x-rays, or the like.

(31) In some embodiments, the second end of the probe **1202** is coupled to the probe seat **1206**. The probe **1202** includes a hollow **1202**A extending though the center of the probe **1202**. In some embodiments, the hollow **1202**A includes a threaded cavity-type interface. The hollow **1202**A allows for alignment amongst the probe **1202**, the probe seat **1206**, and the load cell **1208**. For example, the probe seat **1206** includes a circular ridge **1206**A defining a through hole **1206**B and the circular ridge **1206**A extending upwards into the hollow **1202**A of the probe **1202**. The circular ridge **1206**A includes a lip defining or housing a through hole, and the lip is fitted to extend upwards from the probe seat **1206**. While the probe **1202** is coupled or attached to the probe seat **1206** at one side of the probe seat **1206**, the load cell **1208** is coupled or attached to the opposite side of the probe seat **1206** such that the probe seat **1206** is interposed between the probe **1202** and the load cell **1208**. Accordingly, in some embodiments, the probe seat **1206** is made from any suitable material for transferring the full or almost full force applied to the first end of the probe **1202** to the load cell **1208**, such as, but not limited to, a non-metal material (e.g., polyurethane) and the like. In some embodiments, the probe structure **1200** does not include the probe seat **1206** such that the probe **1202** and the load cell **1208** contact each other.

(32) In some embodiments, the probe seat **1206** is affixed to the probe **1202** through an adhesive layer. The adhesive layer may be any suitable material for securely coupling the probe seat **1206** and the probe **1202** together, such as, but not limited to, an epoxy. In other embodiments, the probe **1202** is secured in the probe seat **1206** by any other suitable connecting means, such as, but not limited to, welding, potting, one or more hooks and latches, one or more separate screws, press fittings, or the like.

(33) In some embodiments, the load cell **1208** is coupled to the probe seat **1206**. Accordingly, the probe seat **1206** may also function as a load cell register. In some embodiments, the load cell **1208** is configured to take measurements of pressure or force exerted on the probe **1202**. In some embodiments, the load cell **1208** is assembled so as to exhibit a preload. For example, the load cell **1208** may be designed to exhibit and include a preload in a range from about 2 Newtons to about 3 Newtons. In some embodiments, because the load cell **1208** is aligned with and proximate the probe **1202** (e.g., coupled to the probe **1202** via the probe seat **1206**), a force exerted against the concave surface of the first end of the probe **1202** (e.g., caused by the concave surface being pressed against a human head), is registered and measured at the load cell **1208**.

(34) In some embodiments, the load cell **1208** is a transducer that is used to create an electrical signal whose magnitude is proportional to the force being measured. In some embodiments, a wire **1212** extending from the load cell **1208** provides electrical signals generated from the load cell **1208**, responsive to the force on the load cell **1208** caused by the probe **1202**. During operation, in some embodiments, when the probe **1202** is pressed against a human skull, a force will also be imparted through the probe seat **1206** to the load cell **1208**, which can be measured and transmitted by the load cell **1208**.

(35) Accordingly, in some embodiments, the probe structure **1200** utilizes the measurements of the load cell **1208** to adjust the pressure exerted by the probe **1202** (e.g., by a robotic apparatus attached to the probe structure **1200**). For example, in some embodiments, the probe structure **1200** decreases the force exerted against a human head by the probe **1202** when the pressure measured by the load cell **1208** is determined to be relatively high (e.g., the pressure measurement exceeds a predetermined threshold). In some embodiments, the predetermined threshold is user-defined and

can be adjusted as desired.

(36) In some embodiments, the load cell **1208** includes a cylindrical protrusion **1208**A extending upwards from the load cell **1208**. The protrusion **1208** passes through the through hole **1206**B of the probe seat **1206** and extends into the hollow **1202**A (or the threaded cavity-type interface of the hollow **1202**A) of the probe **1202**. Accordingly, the probe **1202**, the probe seat **1206**, and the load cell **1208** are capable of remaining aligned such that a maximum amount of forced is transferred from the probe **1202** to the load cell **1208**. In some embodiments, the load cell **1208** is affixed to a bottom inner surface of the probe hub (or gimbal) **1204** through an adhesive layer. The adhesive layer may be any suitable material for securely coupling the load cell **1208** and the probe hub **1204** together, such as, but not limited to, an epoxy, potting, and the like.

(37) In some embodiments, the probe hub **1204** provides a plurality of single axis pivoted supports and interfaces with links and motors to provide a pan and tilt about respective Y and X axes. In some embodiments, the probe hub **1204** is a gimbal as described above. In some embodiments, the probe hub **1204** has a fitted cavity for receiving and housing a portion of the probe **1202**, the probe seat **1206**, and the load cell **1208** to provide further security and alignment of the probe structure **1200**. The cavity of the probe hub (or gimbal) **1204** includes a counter sunk first inner diameter D**1** that corresponds to a location of the load cell **1208** when the load cell **1208** is housed within the probe hub **1204**. The first diameter D**1** is substantially equal to (e.g., slightly larger than) an outer diameter of the load cell **1208** such that the load cell **1208** does not shift radially while housed in the probe hub (or gimbal) **1204**. Accordingly, the load cell **1208** remains axially aligned with the probe seat **1206** and a shaft end of the probe **1202**.

(38) Similarly, the cavity of the probe hub **1204** includes a second inner diameter D**2** that corresponds to a location of the probe **1202** and the probe seat **1206** when the probe **1202** and the probe seat **1206** are housed within the probe hub **1204**. The second inner diameter D**2** is substantially equal to (e.g., slightly larger than) an outer diameter of the shaft end of the probe **1202** and the probe seat **1206** such that the probe **1202** and the probe seat **1206** do not shift radially while housed in the probe hub **1204**. Accordingly, the probe **1202** and the probe seat **1206** remains axially aligned with the load cell **1208**. In some embodiments, the second inner diameter D**2** is greater than the first inner diameter D**1**.

(39) In some embodiments, the probe hub (or gimbal) **1204** has a length long enough to encompass and house the load cell **1208** (e.g., entirely), the probe seat **1206** (e.g., entirely), and a portion (e.g., a substantial portion) of the probe **1202**. In some embodiments, the probe hub **1204** is long enough to house approximately 50% of the length of the body of the probe **1202**. In other embodiments, the probe hub **1204** is long enough to house more than 50% of the length of the body of the probe **1202** (e.g., about 55%, 60%, 65%, or more). In other embodiments, the probe hub **1204** houses less than 50% of the length of the body of the probe **1202** (e.g., about 45%, 40%, 35%, or less). In particular embodiments, the probe hub **1204** house about 33% of the length of the body of the probe **1202**.

(40) In some embodiments, the probe hub **1204** includes a lengthwise slot **1204**A. The slot **1204**A may extend along the full length of the body of the probe hub **1204**. In other embodiments, the slot **1204**A extends along less than the full length of the body of the probe hub **1204**. The slot **1204**A is configured to receive and retain wires and cables originating from the components housed within the probe hub **1204**. For example, the slot **1204**A receives and retains the wire **1212** originating from the load cell **1208** and a cable **1210** originating from the probe **1202**. Accordingly, the wire **1212** and the cable **1210** can be aligned and secured (e.g., during assembly and outside of the probe hub or gimbal **1204**) so that they do not become an obstacle during assembly or operation of the probe structure **1200**. In some embodiments, the wire **1212** remains static in the slot **1204**A, while the cable **1210** is configured to move within the slot **1204**A (e.g., flex or otherwise move along the length of the slot **1204**A). In some embodiments, the probe hub **1204** further includes a gimbal interface **1214** for attaching to gimbal linkages that can control the probe structure **1200**.

(41) FIG. **13**A illustrates a perspective view of an integrated probe structure **1300** according to

various embodiments. FIG. **13**B illustrates a transparent probe housing in a perspective view of the integrated probe structure **1300** shown in FIG. **13**A according to various embodiments. FIG. **13**C illustrates an exploded view of the integrated probe structure **1300** shown in FIG. **13**A according to various embodiments.

(42) The probe structure **1300** includes a probe housing **1302**, a probe **1304**, an interconnection structure **1306**, and a load cell **1308**. In some embodiments, the probe structure **1300** includes an end effector, for example, used in conjunction with a robot arm (e.g., a 6-axis robot arm). The probe housing **1302** covers and houses the probe **1304**, the interconnection structure **1306**, and the load cell **1308**. The probe **1304** extends through a top opening of the probe housing **1302**. The interconnection structure **1306** provides the framework of the probe structure **1300** for securing the components together. The load cell **1308** is located adjacent to the probe **1304** (e.g., directly underneath the probe **1304**). The probe structure **1300** can be used in connection with a robotic arm (e.g., a robotic arm including multiple degrees of freedom, such as, but not limited to, six degrees of freedom).

(43) Although the present disclosure illustrates and describes an integrated probe system including a load cell for detecting force exerted against a probe in a single axis (e.g., along an axis that is perpendicular to the upper surface of the probe facing a scanning surface), in some embodiments, the load cell and the integrated probe system may be configured to detect forces in a plurality of axes. For example, the integrated probe system may be configured to detect force exerted against the probe along two axes, three axes, four axes, five axes, or six axes. In some embodiments, the probe is continuously adjusted to maintain a normal position along a scanning surface using a load cell that detects force along a plurality of axes (e.g., along six different axes).

(44) As used herein, the terms “approximately,” “substantially,” “substantial” and “about” are used to describe and account for small variations. When used in conjunction with an event or circumstance, the terms can refer to instances in which the event or circumstance occurs precisely as well as instances in which the event or circumstance occurs to a close approximation. For example, when used in conjunction with a numerical value, the terms can refer to a range of variation less than or equal to ±10% of that numerical value, such as less than or equal to ±5%, less than or equal to ±4%, less than or equal to ±3%, less than or equal to ±2%, less than or equal to ±1%, less than or equal to ±0.5%, less than or equal to ±0.1%, or less than or equal to ±0.05%. For example, two numerical values can be deemed to be “substantially” the same or equal if a difference between the values is less than or equal to ±10% of an average of the values, such as less than or equal to ±5%, less than or equal to ±4%, less than or equal to ±3%, less than or equal to ±2%, less than or equal to ±1%, less than or equal to ±0.5%, less than or equal to ±0.1%, or less than or equal to ±0.05%.

(45) The above used terms, including “attached,” “connected,” “secured,” and the like are used interchangeably. In addition, while certain embodiments have been described to include a first element as being “coupled” (or “attached,” “connected,” “fastened,” etc.) to a second element, the first element may be directly coupled to the second element or may be indirectly coupled to the second element via a third element.

(46) The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” Unless specifically stated otherwise, the term “some” refers to one or more. All structural and functional equivalents to the elements of the various aspects described throughout the previous description that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims.

Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed as a means plus function unless the element is expressly recited using the phrase “means for.”

(47) It is understood that the specific order or hierarchy of steps in the processes disclosed is an example of illustrative approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the previous description. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

(48) The previous description of the disclosed implementations is provided to enable any person skilled in the art to make or use the disclosed subject matter. Various modifications to these implementations will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of the previous description. Thus, the previous description is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

Claims

1. A system, comprising: a probe configured to emit acoustic energy and comprising a hollow cavity disposed within a center portion of the probe; a sensor configured to output a signal indicating an amount of force exerted against the probe when the probe is against a surface of a subject and comprising a cylindrical protrusion extending into the hollow cavity to align the probe and the sensor; and a probe hub, wherein the probe, the sensor, and the probe hub are aligned through an axis.
2. The system of claim 1, wherein the sensor further comprises a load cell.
3. The system of claim 1, wherein the sensor is configured to detect the amount of force exerted against the probe along a plurality of axes.
4. The system of claim 1, wherein the probe further comprises a Transcranial Doppler (TCD) probe.
5. The system of claim 1, wherein the probe hub comprises at least one motor.
6. The system of claim 1, wherein the probe hub comprises an opening through which the probe extends, the opening and the probe align along the axis.
7. The system of claim 1, wherein the probe hub encloses at least 50% of a body of the probe.