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(54) **WEARABLE TONOMETER WITH RESILIENTLY DEFORMABLE PAD**

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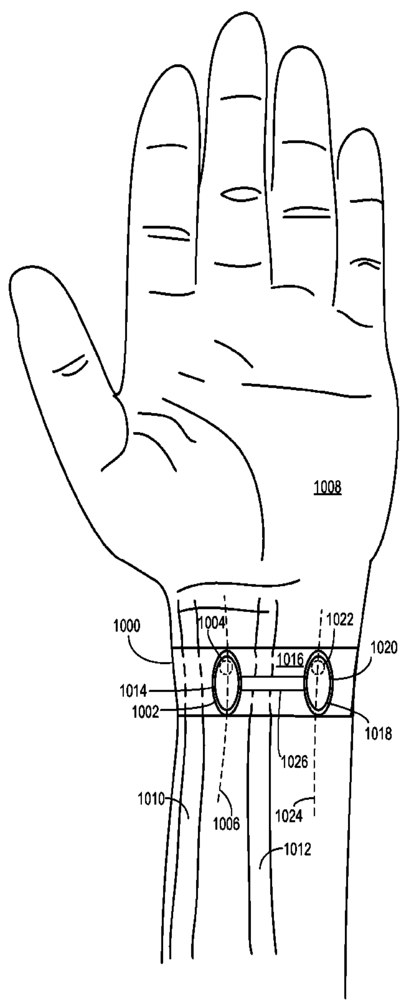
CPC *A61B 5/02108* (2013.01); *A61B 5/6831* (2013.01); *A61B 5/02141* (2013.01); *A61B 5/6843* (2013.01); *A61B 5/6824* (2013.01)

(57) **ABSTRACT**

A wearable tonometer is provided, comprising a sensing device. The sensing device may include a pressure sensor configured to measure a pulse pressure wave in an artery of user. The sensing device may include a resiliently deformable pad or pad-cap structure positioned on a sensing surface side of the pressure sensor and configured to contact skin of the user proximate the artery. The wearable tonometer may include a band that holds the sensing device in contact with the skin. In some embodiments, the sensing device may include a rigid internal structure configured to transmit the pulse pressure wave. In some embodiments, the wearable tonometer may include an adjustment mechanism configured to move the sensing device relative to the band. In some embodiments, the wearable tonometer may include a second resiliently deformable pad-cap structure, and a solid plate attached to the resiliently deformable pad-cap structures and the band.



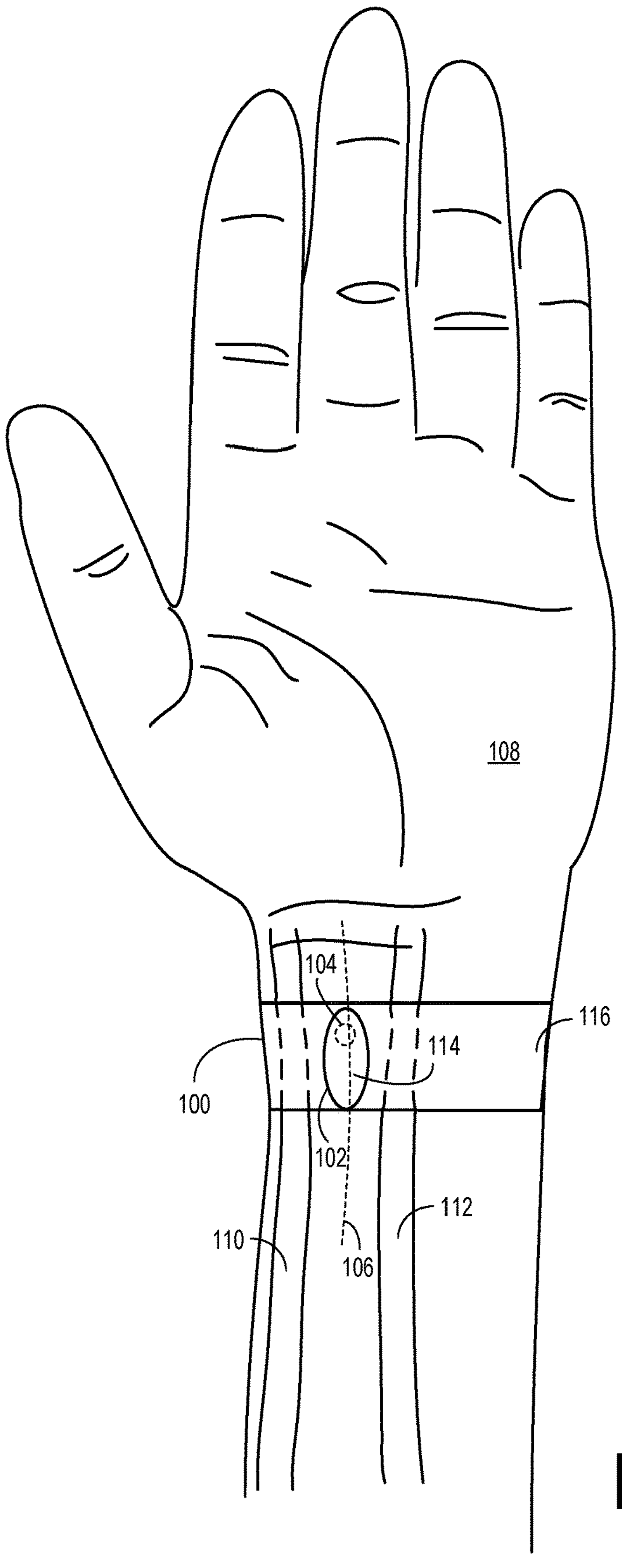


FIG. 1

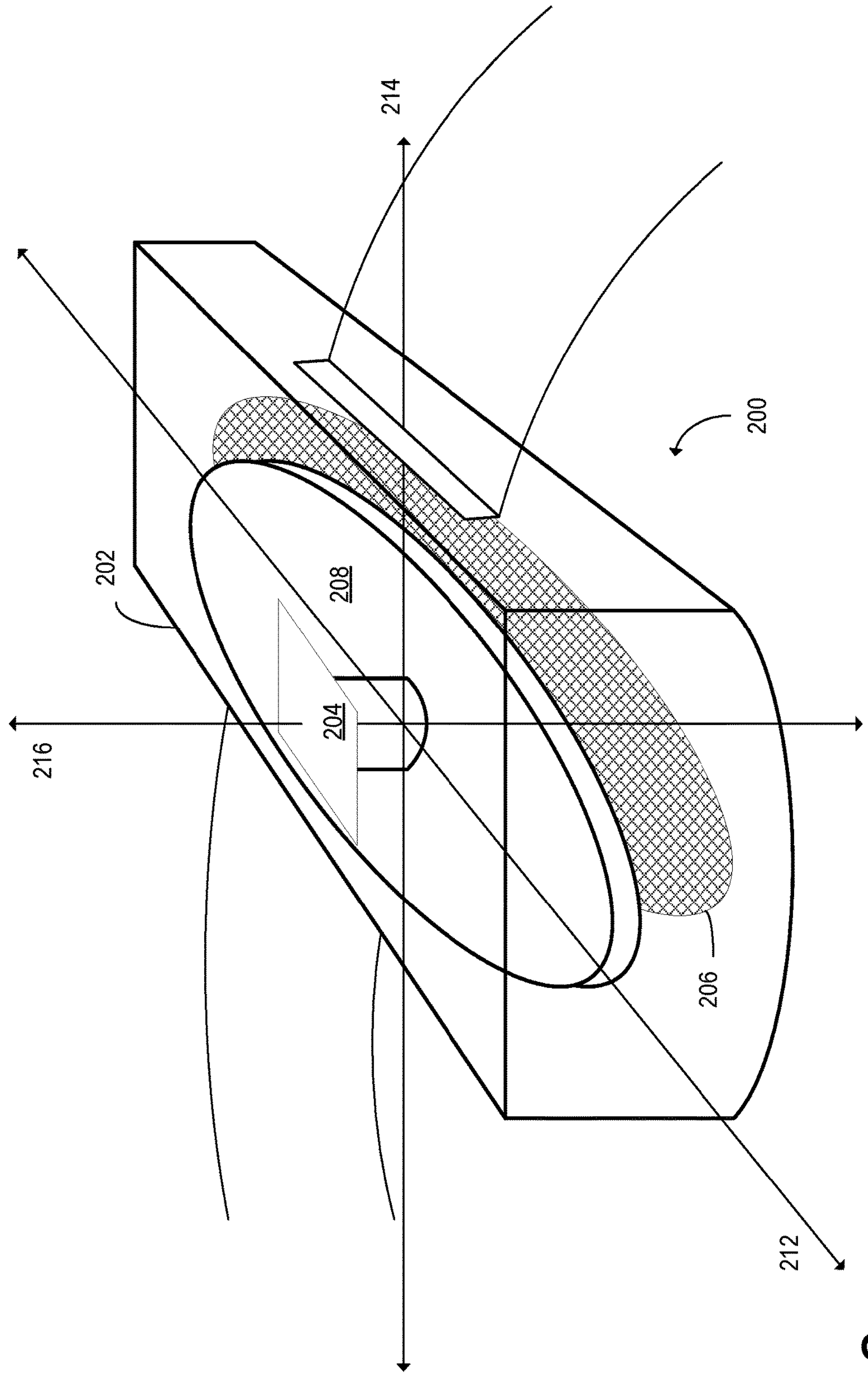


FIG. 2

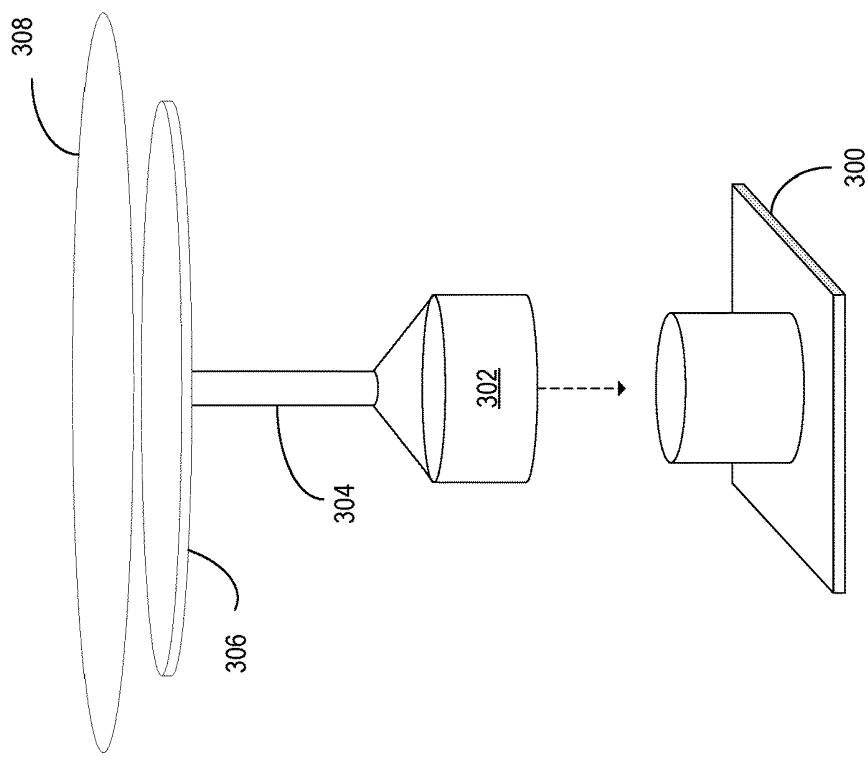


FIG. 3

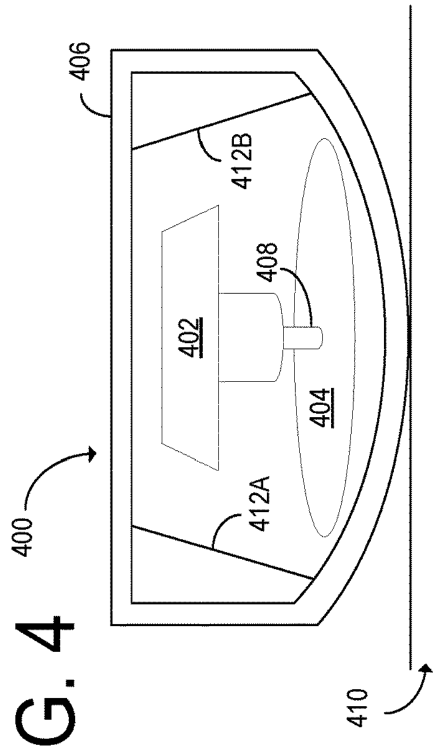


FIG. 4

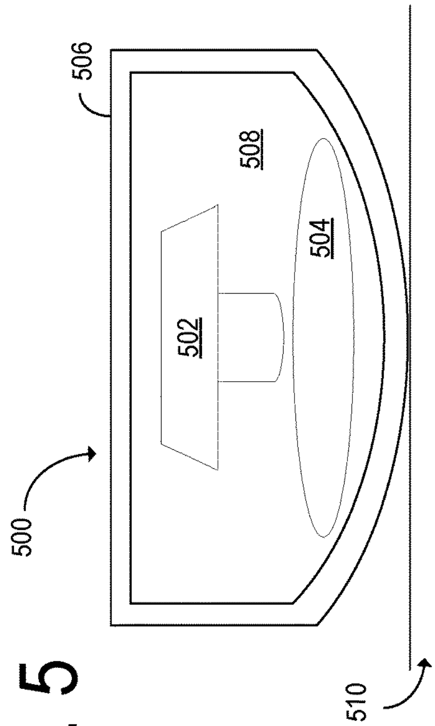


FIG. 5

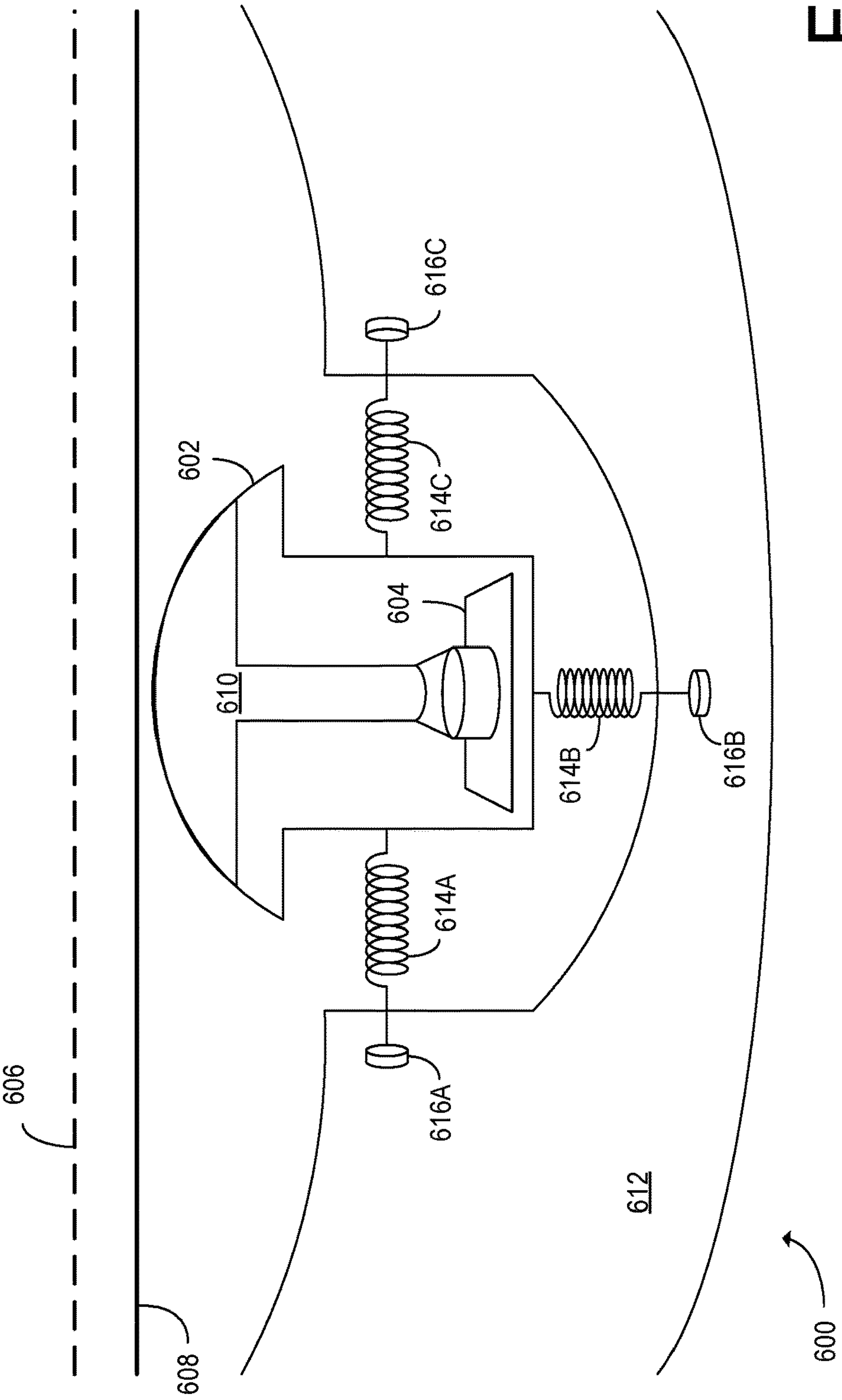


FIG. 6

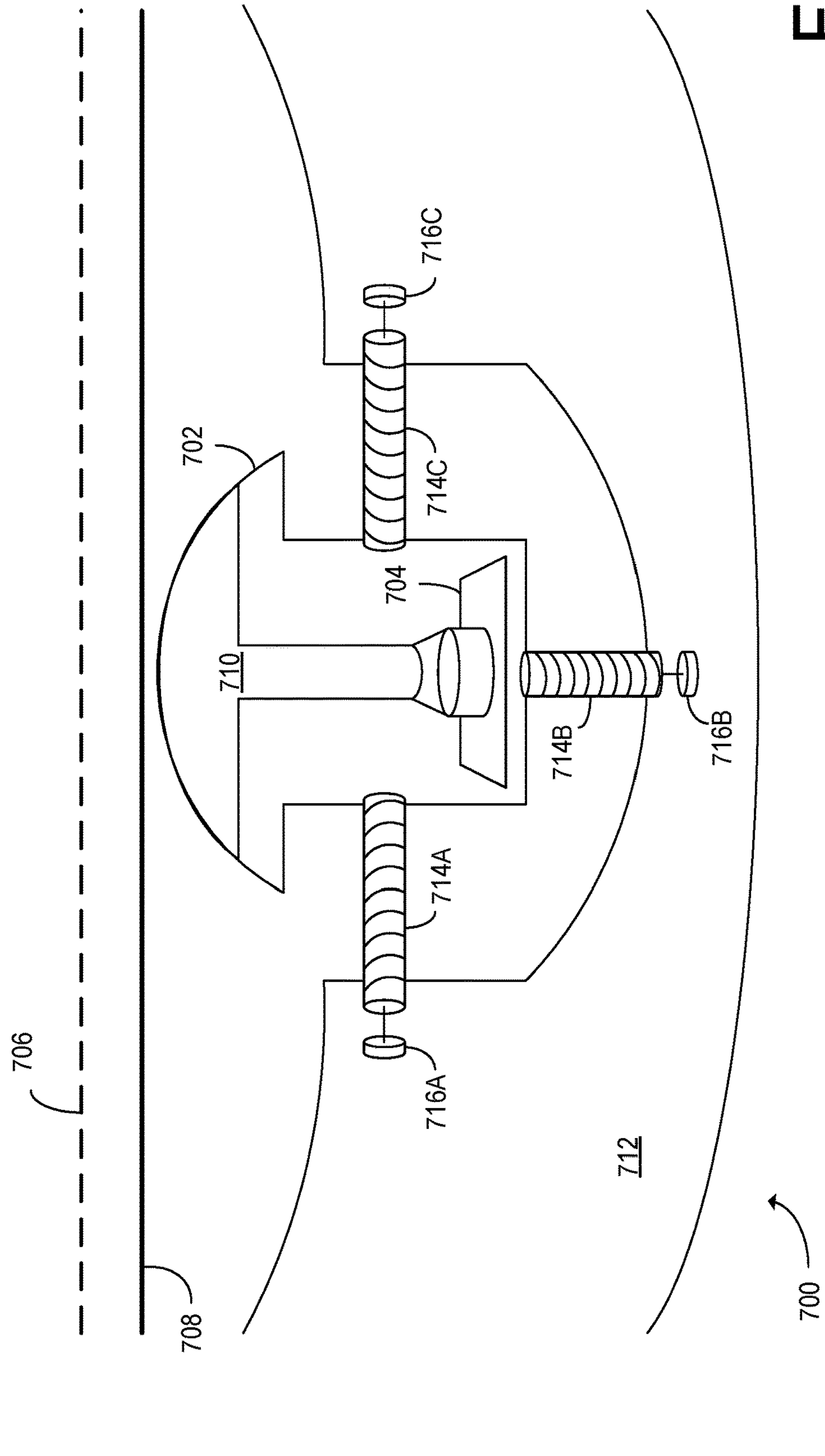


FIG. 7

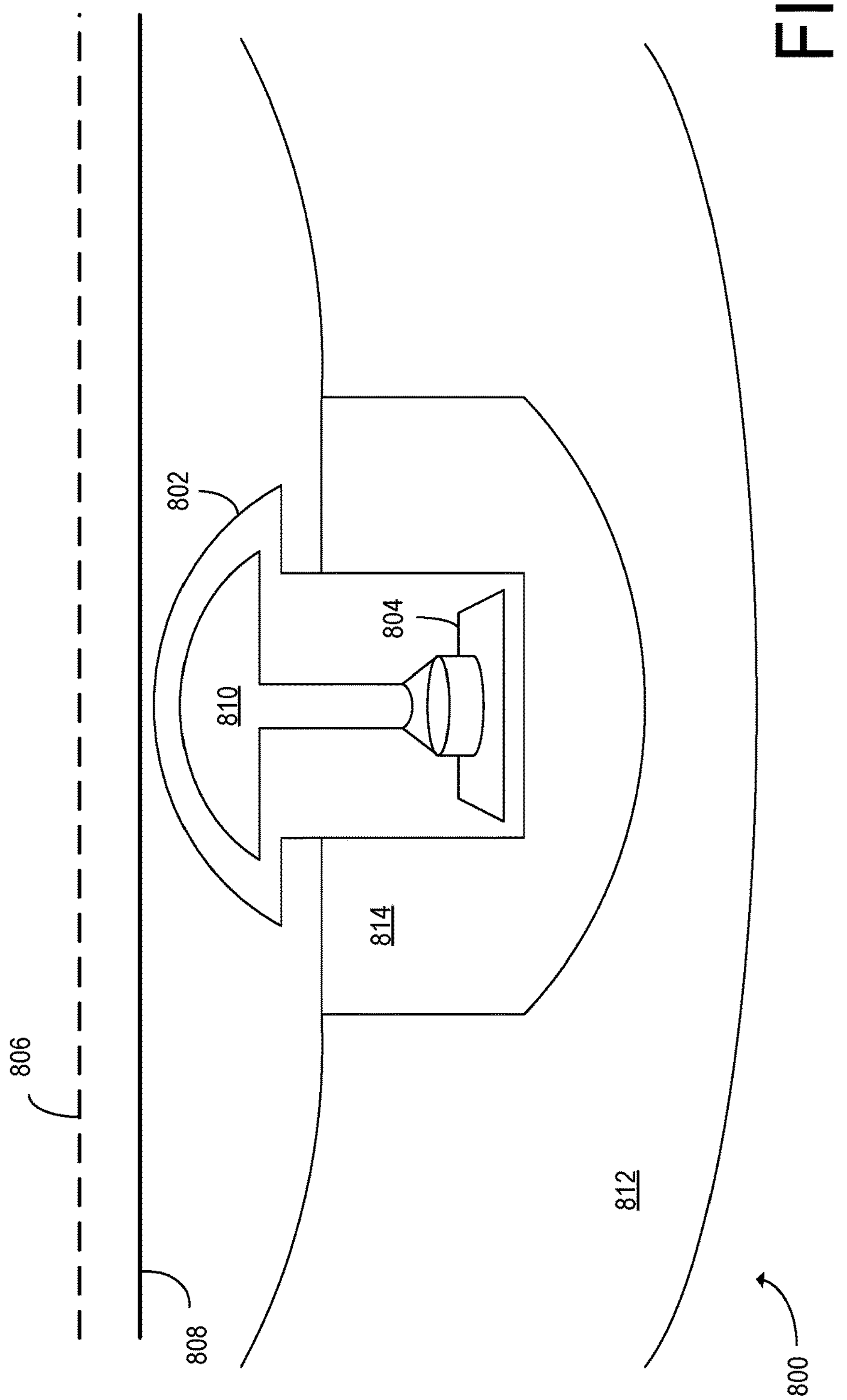


FIG. 8

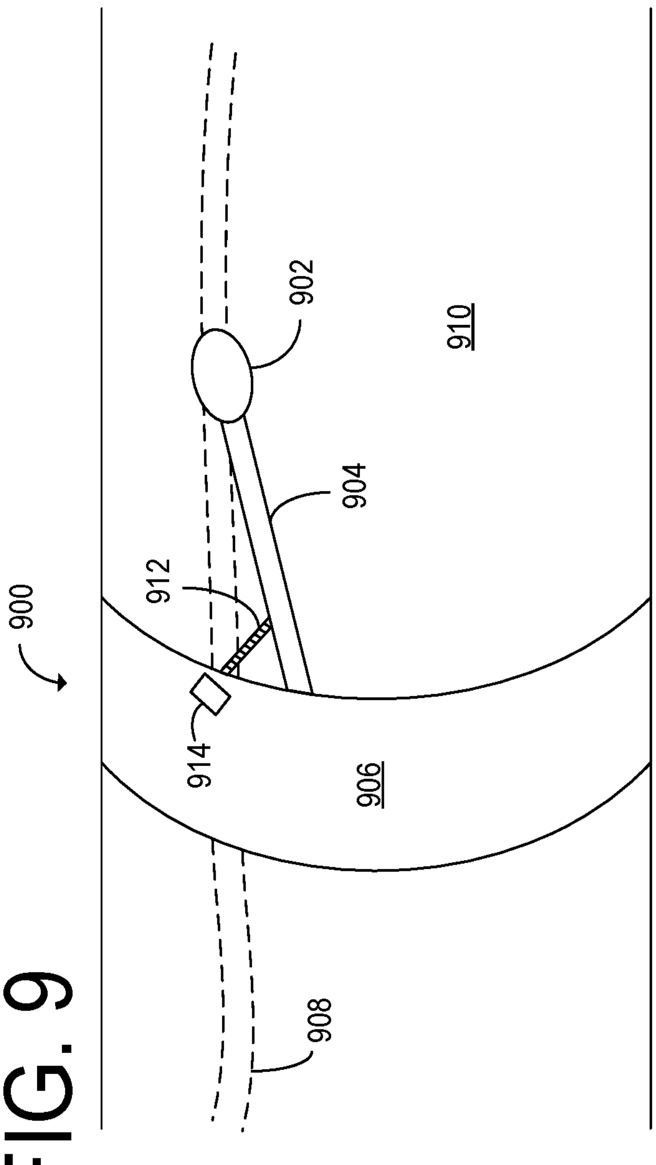


FIG. 9

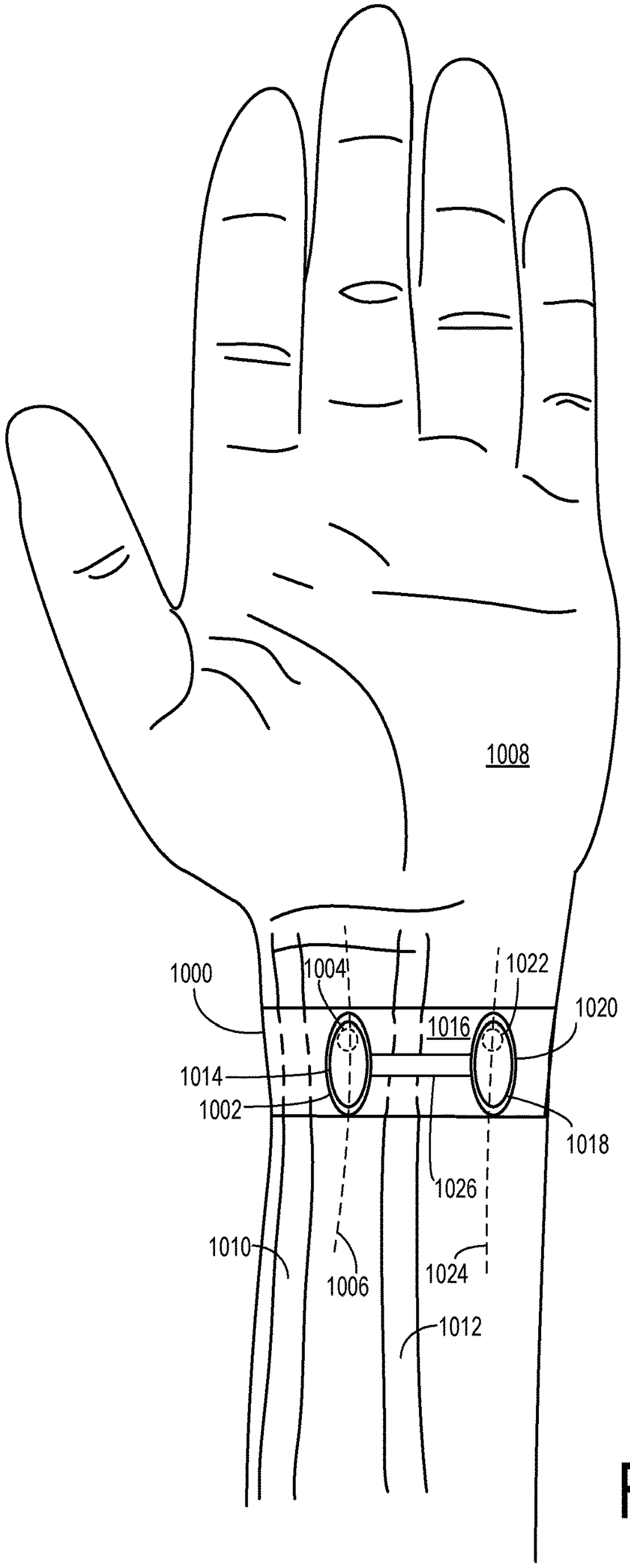

1008
1000
1004
1022
1020
1016
1014
1002
1018
1026
1010
1006
1024
1012

FIG. 10

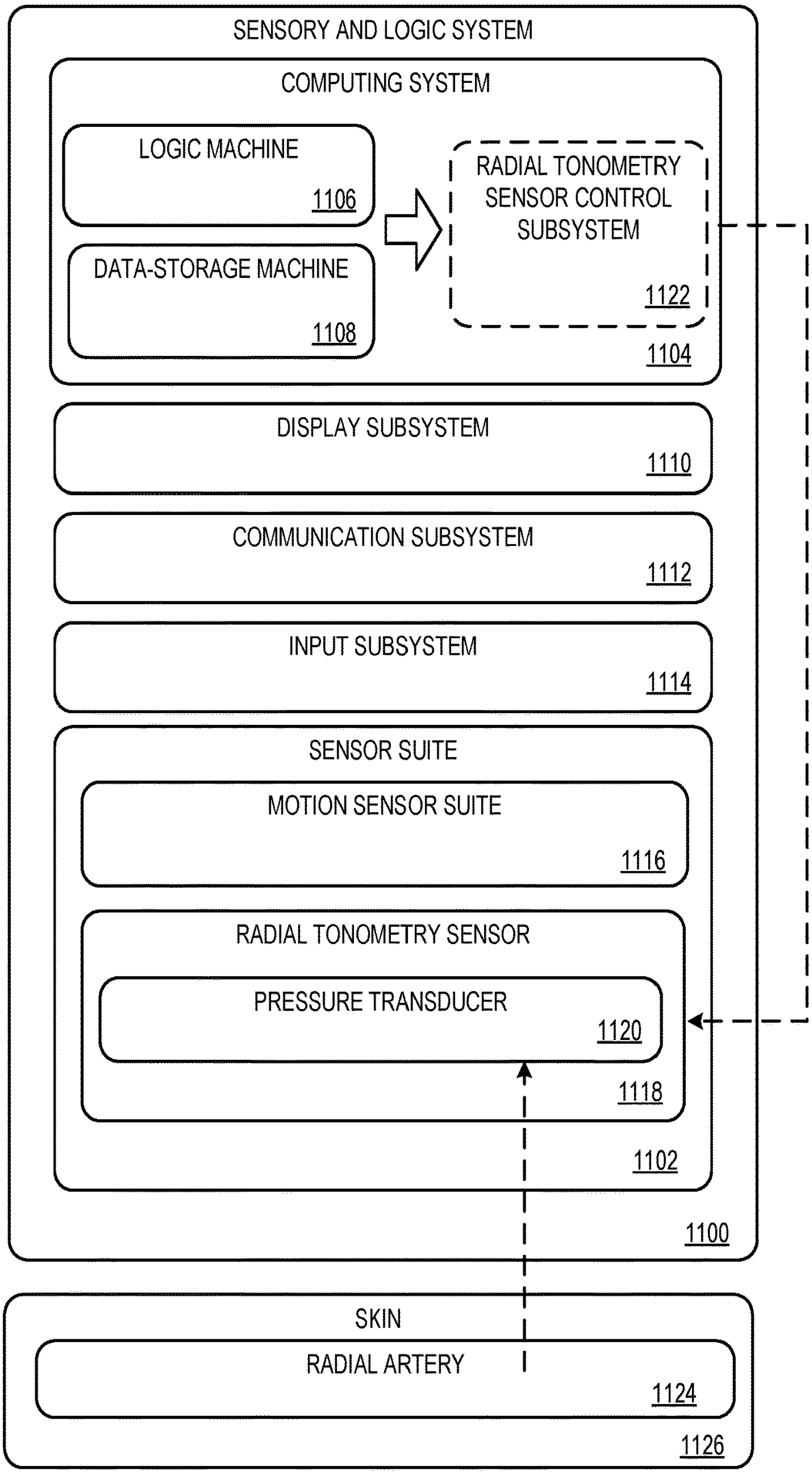

SENSORY AND LOGIC SYSTEM
COMPUTING SYSTEM
LOGIC MACHINE
1106
DATA-STORAGE MACHINE
1108
RADIAL TONOMETRY SENSOR CONTROL SUBSYSTEM
1122
1104
DISPLAY SUBSYSTEM
1110
COMMUNICATION SUBSYSTEM
1112
INPUT SUBSYSTEM
1114
SENSOR SUITE
MOTION SENSOR SUITE
1116
RADIAL TONOMETRY SENSOR
PRESSURE TRANSDUCER
1120
1118
1102
1100
SKIN
RADIAL ARTERY
1124
1126

FIG. 11

WEARABLE TONOMETER WITH RESILIENTLY DEFORMABLE PAD

BACKGROUND

[0001] When the left ventricle of the heart compresses and expels blood into the arteries, a pressure wave is created. This wave travels along the arteries in the body, and its shape at any point in the arterial system is affected by the overall blood pressure, the level of vasodilation or vasoconstriction, the state of the endothelial lining of the arteries, the buildup of plaque therein, and the resulting stiffness or compliance of the arteries from the latter to factors. A pressure sensor at a given point in an artery can transduce this pressure as it changes with time and the resulting pulse pressure wave can be recorded.

[0002] The pulse pressure wave may be detected invasively or non-invasively. The invasive form of sensing device is a catheter inserted into the artery with a pressure sensor on the tip. Invasive sensing can be used in any artery but is typically used in the descending aorta for so-called "central" measurements. The non-invasive approach is to place a pressure sensor on the surface of the skin over an artery and to applanate the artery, i.e., apply force such that the surface of the artery is at least partial deformed so that the sensor can capture the pressure signal within the artery. The latter is most effective for arteries that are present near the surface of the skin, including the radial (wrist), carotid (neck), and femoral (thigh) arteries. A pressure sensor used to transduce pulse-pressure waves in this way is referred to as a tonometer.

SUMMARY

[0003] A wearable tonometer is provided, comprising a sensing device. The sensing device may include a pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user. The sensing device may further include a resiliently deformable pad or pad-cap structure positioned on a sensing surface side of the pressure sensor and configured to contact skin of the user proximate the artery. The wearable tonometer may further include a band that holds the sensing device in contact with the skin of the user. In some embodiments, the sensing device may further include a rigid internal structure positioned at least partially within the resiliently deformable pad and configured to transmit the pulse pressure wave on its way to the pressure sensor. In some embodiments, the wearable tonometer may further include an adjustment mechanism configured to move the sensing device relative to the band. The adjustment mechanism may be configured to move the sensing device in a plane tangent to the skin of the user while the position of the band fixed. In some embodiments, the wearable tonometer may further include a second resiliently deformable pad-cap structure adjacent to skin of the user, and a solid plate attached to the first resiliently deformable pad-cap structure, the second resiliently deformable pad-cap structure, and the band.

[0004] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** depicts a wearable tonometer including a sensing device, according to one embodiment of the present disclosure.

[0006] FIG. **2** depicts a wearable tonometer with a sensing device including a rigid internal structure, according to one embodiment of the present disclosure.

[0007] FIG. **3** depicts structures that may be included in the sensing device of FIGS. **1** and **2**, according to one embodiment of the present disclosure.

[0008] FIG. **4** depicts a cross-sectional view of a sensing device including a rigid internal structure, according to one embodiment of the present disclosure.

[0009] FIG. **5** depicts a cross-sectional view of a sensing device including a pressurized fluid contained within the sensing device, according to one embodiment of the present disclosure.

[0010] FIG. **6** depicts a wearable tonometer including an adjustment mechanism, wherein the adjustment mechanism includes biasing members, according to one embodiment of the present disclosure.

[0011] FIG. **7** depicts a wearable tonometer including an adjustment mechanism, wherein the adjustment includes screw members, according to one embodiment of the present disclosure.

[0012] FIG. **8** depicts a wearable tonometer including an adjustment mechanism, wherein the adjustment mechanism includes a pressurized fluid, according to one embodiment of the present disclosure.

[0013] FIG. **9** depicts a wearable tonometer including an adjustment mechanism, wherein the adjustment mechanism includes a cantilever, according to one embodiment of the present disclosure.

[0014] FIG. **10** depicts a wearable tonometer including a first sensing device, a second sensing device, and a solid plate, according to one embodiment of the present disclosure.

[0015] FIG. **11** schematically depicts a sensory and logic system for use with a wearable tonometer, according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0016] The inventors have recognized that traditional tonometers as discussed above require careful placement and manipulation by a skilled technician. Wearable tonometers, which are intended to be easier for patients to place on their own, either tend to be very sensitive to precise placement or uncomfortably bulky. This is because the geometry of the relevant portion of the body, the region where the artery is near the surface of the skin, varies greatly between individuals. In particular, the precise position and depth of any given artery is quite different from patient to patient. A device a small point-like sensor thus requires careful positioning, and thus far the state of the art for avoiding the need for careful positioning is a large, hard, and uncomfortable protrusion that pushes down on the entire region. These shortcomings make existing ambulatory tonometers, which are intended to be worn throughout the day and must be placed correctly by the patient, impractical to use.

[0017] To address these shortcomings, herein is provided a wearable tonometer for ambulatory tonometry which can achieve easy placement without discomfort. FIG. **1** depicts a wearable tonometer **100**, according to one embodiment of the present disclosure. The wearable tonometer **100** comprises a sensing device **102**, which includes a pressure sensor **104**. The pressure sensor **104** is configured to measure, a pulse pressure wave of blood pressure in an ante **106** of a user **108**. In the embodiment depicted in FIG. **1**, the artery **106** is a radial artery and the sensing device **102** sits between the radius **110** and flexor carpi radialis tendon **112** of the user **108**. The wearable tonometer **100** may additionally or instead be configured to measure a pulse pressure wave of blood pressure in other arteries of the user **108**.

[0018] The wearable tonometer **100** also includes a resiliently deformable pad **114** positioned on a sensing surface side of the pressure sensor **104** and configured to contact skin of the user **108** proximate the artery **106**. The resiliently deformable pad **114** may be composed of cloth, foam, elastomeric material, or some other resiliently deformable material or combination of materials. The resiliently deformable pad **114** may applanate the skin of the user **108** proximate the artery **106**, applying a force to the skin so that the shape of the skin is slightly deformed. Applanating the skin proximate the artery **106** allows the pressure sensor **104** to detect the pulse pressure wave over a larger surface. Since the precise location of the artery **106** may vary between different users, detecting the pulse pressure wave over a larger surface makes the quality of the measurement made by the wearable tonometer **100** less dependent on the precise placement of the sensing device **102**. This allows the user **108** to more easily place the wearable tonometer **100** in a location on the skin at which it will provide an accurate pulse pressure wave measurement. In addition, distributing the applanating force over a larger area may allow the sensing device **102** to continue to detect a pulse pressure wave if the wearable tonometer **100** moves relative to the skin of the user **108**. The resiliently deformable pad **114** may also integrate the pulse pressure wave over the body of the sensing device **102**, thus concentrating force contributions from a wider area into the pressure sensor **104**. By distributing the applanating force applied by the wearable tonometer **100** to the skin, the resiliently deformable pad **114** may also make the wearable tonometer **100** more comfortable for the user **108** to wear.

[0019] The wearable tonometer **100** further includes a band **116** that holds the sensing device **102** in contact with the skin of the user **108**. In the embodiment shown in FIG. **1**, the band **116** is a wrist band. The band **116** may configured to have an adjustable tightness, so as to allow the user **108** to adjust the amount of pressure applied o the skin by the wearable tonometer **100**.

[0020] An example embodiment of a wearable tonometer **200** is shown in FIG. **2**. The wearable tonometer **200** includes a sensing device **202**, including a pulse pressure sensor **204**. The pulse pressure sensor **204** may be a piezoresistive pressure sensor with an electrical resistance that changes in response to pressure, or may be some other variety of pressure sensor. The sensing device **202** further includes a resiliently deformable pad **206**. The resiliently deformable pad **206** has a convex skin-contacting surface that is elongated along a longitudinal axis **212**. The longitudinal axis **212** may be in line with an artery when the wearable tonometer **200** is worn by a user. The resiliently deformable pad **206** may cover the entire sensing device **202**, or alternately may cover only a portion of the sensing device **202** proximate the artery.

[0021] According to the embodiment of FIG. **2**, the sensing device **202** also includes a rigid internal structure **208** positioned at least partially within the resiliently deformable pail **206**. The rigid internal structure **208** is configured to transmit a pulse pressure wave on its way to the pressure sensor **204**. The rigid internal structure **208** is composed of a material that is more rigid than the material of which the resiliently deformable pad **206** is composed. The pulse pressure wave may therefore undergo less attenuation when traveling through the rigid internal structure **208** than when traveling through the resiliently deformable pad **206**. By including the rigid internal structure **208** in addition to the resiliently deformable pad **206**, the sensitivity of the sensing device **202** is increased while retaining the advantages of using a resiliently deformable pad **206**.

[0022] As shown in FIG. **2**, the rigid internal structure **208** may have a flat, plate-like shape that is elongated along the longitudinal axis **212**. The rigid internal structure **208** is not limited to having an elliptical perimeter, but may also have a rectangular perimeter, a perimeter shape that includes wing-like protrusions, or some other perimeter shape.

[0023] FIG. **3** depicts structures that may be included in the sensing device of FIGS. **1** and **2**. The pressure sensor **300** may be covered by a resiliently deformable cap **302** on the side of the pressure sensor **300** proximate the artery of the user. The resiliently deformable cap **302** may protect the pressure sensor **300** from damage and may transmit pulse pressure waves to the pressure sensor **300**. The resiliently deformable cap **302** may be a pressurized bladder filled with air, some other fluid, or an elastomeric material. In some embodiments, the resiliently deformable cap **302** may be integrated with a resiliently deformable pad **308** to form a resiliently deformable pad-cap structure.

[0024] The embodiment depicted in FIG. **3** includes a rigid internal structure **306** and a plunger structure **304** coupled to the rigid internal structure **306**. The plunger structure **304** is configured to transmit a pulse pressure wave from the rigid internal structure **306** to the pressure sensor **300**. The pressure sensor **300** is directly or indirectly coupled to the plunger structure **304** on a side of the plunger structure **304** opposite the rigid internal structure **306**. The resiliently deformable pad **308** covers the rigid internal structure **306** at least on a side of the rigid internal structure **306** opposite the plunger structure **304**.

[0025] A cross-sectional view of a sensing device **400** is depicted in FIG. **4**, according to an embodiment of the present disclosure. The sensing device **400** includes a pressure sensor **402**, a rigid internal structure **404**, and a resiliently deformable pad **406**. The sensing device **400** further includes a plunger structure **408** coupled to the rigid internal structure **404**. In the embodiment of FIG. **4**, the plunger structure **408** is coupled directly to the pressure sensor **402**. Coupling the plunger structure **408** directly to the pressure sensor **402** has the advantage of making the sensing device **400** more sensitive to pulse pressure waves received by the rigid internal structure **404** than if the pressure sensor **402** were indirectly coupled to the plunger structure **408**, since pulse pressure waves undergo less damping between the rigid internal structure **404** and the pressure sensor **402**.

[0026] However, the resilient deformable pad **406** may still protect the pressure sensor **402** from damage by damping forces exerted on it.

[0027] The plunger structure **408** may be oriented along an axis normal to a plane tangent to a skin contacting surface of the resiliently deformable pad **406** at a point of contact with skin **410** of a user. This orientation of the plunger structure **408** causes the pressure sensor **402** to be aligned with the component of the pulse pressure wave that travels outward from the skin **410** of the user.

[0028] The rigid internal structure **404** may be prestressed by the resiliently deformable pad **406** and may apply a baseline pressure to the pressure sensor **402**. This prestress clay be applied by tensioning structures **412**A and **412**B that put tension on the resiliently deformable pad **406**. The tension applied to the resiliently deformable pad **406** may cause the resiliently deformable pad **406** to, in turn, put pressure on the rigid internal structure **404**. Via the rigid internal structure **404**, pressure may be applied to the pressure sensor **402** so as to provide a constant biasing signal.

[0029] In another embodiment not shown, the resiliently deformable pad **406** may be divided into a top piece and a bottom piece. The top piece and the bottom piece may be attached to each other, for example with glue, in such a way that the rigid internal structure **404** is prestressed and a baseline pressure is applied to the pressure sensor **402**.

[0030] A cross-sectional view of a sensing device **500** is depicted in FIG. **5**, according to another embodiment of the present disclosure. The sensing device **500** of FIG. **5** differs from the sensing device **400** of FIG. **4** in that while the rigid internal structure **404** is coupled directly to the pressure sensor **402** by the plunger structure **408** in FIG. **4**, a pressure sensor **502** is coupled indirectly to a rigid internal structure **504** in FIG **5**. The sensing device **500** of FIG. **5** does not include a plunger structure. Instead, the pressure sensor **502** is coupled to a pressurized fluid **508** contained within the sensing device **500**. The pressurized fluid **508** may be air, or may be some other fluid. The use of a pressurized fluid **508**, rather than direct coupling between the pressure sensor **502** and a rigid internal structure **504**, has the advantage of better protecting the pressure sensor **502**. However, more of the force exerted by the pulse pressure wave on the sensing device **500** may be dissipated via damping in the pressurized fluid **508** than would be dissipated in an embodiment which direct coupling is used.

[0031] According to another embodiment of the present disclosure, depicted in cross section in FIG. **6**, a wearable tonometer **600** is provided, including a sensing device **602**. The sensing device **602** includes a pressure sensor **604** configured to measure a pulse pressure wave of blood pressure in an artery **606** of a user **608**. The sensing device **602** further includes a resiliently deformable pad-cap structure **610** positioned between the pressure sensor **604** and skin of the user **608** proximate the artery **606**. The resiliently deformable pad-cap structure **610** may consist of cloth, foam, an elastomeric material, or some other resiliently deformable material or combination of materials. In addition, the resiliently deformable pad-cap structure **610** may include a pressurized bladder filled with air, some other fluid, or an elastomeric material.

[0032] The resiliently deformable pad-cap structure **610** may be configured to applanate the skim of the user **608** such that the sensing device **602** contacts a wide enough area of skin on the user **608** that the wearable tonometer **600** may make an accurate blood pressure measurement without requiring precise placement. By distributing force exerted on the skin of the user **608** by the sensing device **602** over a larger area, the resiliently deformable pad-cap structure **610** may make the wearable tonometer **600** more comfortable to wear for a long period of time. Furthermore, the resiliently deformable pad-cap structure **610** may protect the pressure sensor **604** by damping forces exerted on the sensing device **602**. Since the wearable tonometer **600** may be worn while the user **608** engages in a wide range of possible activities, it is useful for the resiliently deformable pad-cap structure **610** to protect the pressure sensor **604** and other components of the wearable tonometer **600** that may be fragile.

[0033] The wearable tonometer **600** includes a band **612** that holds the sensing device **602** in contact with the skin of the user **608**. The wearable tonometer **600** further includes an adjustment mechanism configured to move the sensing device **602** relative to the band **612**. In the embodiment of FIG. **6**, the adjustment mechanism includes biasing members **614**A, **614**B, and **614**C. Although three biasing members are depicted, other numbers of biasing members may be used. The adjustment mechanism is configured to move the sensing device **602** in a plane tangent to the skin of the user **608** while the position of the band **612** remains fixed. In the current embodiment, the biasing members **614**A, **614**B, and **614**C are configured to move the sensing device **602** in a plane tangent to the skin of the user **608**. For example, in response to a displacement of the sensing device **602** to the right relative to the band **612**, the biasing members **614**A, **614**B, and **614**C may exert forces in the direction of an equilibrium position to the left. Adjustments made by the adjustment mechanism to the position of the sensing device **602** may allow the sensing device **602** to remain in a location proximate the artery **606** of the user **608** when the wearable tonometer **600** is worn during activities that include movement. The adjustment mechanism may also make the sensing device **602** more comfortable for the user **608** by allowing movement of the sensing device **602** relative to the band **612** when the wrist of the user **608** bends.

[0034] In addition to moving the sensing device **602** in a plane tangent to the skin of the user **608**, the adjustment mechanism may be further configured to move the sensing device **602** along an axis normal to the plane tangent to the skin of the user **608**. For example, in response to a displacement of the sensing device **602** downward relative to the band **612** due to an ease in pressure exerted on the sensing device **602** by the skin of the user **608**, the biasing members **614**A, **614**B, and **614**C may exert forces in the direction of an equilibrium position upward. Adjusting the position of the sensing device **602** in this way decreases the applanation pressure and may make the wearable tonometer **600** more comfortable to wear, in comparison to embodiments that do not include a mechanism configured to adjust the applanation pressure. Additionally, in response to a displacement of the sensing device **602** upward relative to the band **612** due to an increase in pressure exerted on the sensing device **602** by the skin of the user **608**, the biasing members **614**A, **614**B, and **614**C may exert forces in the direction of an equilibrium position downward. Such an adjustment may allow the sensing device **602** to remain in contact with the skin of the user **608** when the band **612** is moved away from the skin.

[0035] In addition the biasing members **614**A, **614**B, and **614**C, the adjustment mechanism of the wearable tonometer **600** includes electromagnetic actuators **616**A, **616**B, and **616**C. Each electromagnetic actuator is configured to move its respective biasing member along an axis of that biasing member. The electromagnetic actuators **616**A, **616**B, and **616**C may dynamically move the sensing device **602** in a plane tangent to the skin of the user **608** so that the sensing device **602** is in contact with the skin covering a surface artery **606** of the user **608**. By moving the biasing members, the electromagnetic actuators may move the sensing device **602** in a plane tangent to the skin of the user **608** or along the axis normal to that plane. When the electromagnetic actuators **616**A, **616**B, and **616**C are not moving their respective biasing members, the biasing members may passively adjust the position of the sensing device **602** as described above.

[0036] In some embodiments, the wearable tonometer **600** may perform intermittent blood pressure measurements rather than continuously measuring a pulse pressure wave of blood pressure in the artery **606** of the user **608**. In such embodiments, the adjustment mechanism may be configured to receive a starting signal indicating a beginning of a blood pressure measurement, in response to receiving the starting signal, the adjustment mechanism may be configured to increase the applanation pressure of the sensing device **602** against the skin of the user **608**. The adjustment mechanism may increase the applanation pressure by moving the biasing members **614**A, **614**B, and **614**C using the electromagnetic actuators **616**A, **616**B, and **616**C. The adjustment mechanism may be further configured to receive an ending signal indicating an ending of the blood pressure measurement. In response to receiving the ending signal, the adjustment mechanism may be configured to decrease the applanation pressure of the sensing device **602** against the skin of the user **608**. By increasing the applanation pressure when blood pressure measurements are taken and holding the sensing device **602** in contact with the skin of the user **608** when measurements are not being taken, the adjustment mechanism may make the wearable tonometer **600** more comfortable for long-term use while still providing sufficient applanation pressure to allow for accurate blood pressure measurements when measurements are taken.

[0037] In some embodiments, the adjustment mechanism may be configured to ac just the applanation pressure of the sensing device **602** against the skin of the user **608** based at least in part on a pressure measurement made by the pressure sensor **604**. For example, the pressure sensor **604** may detect that the applanation pressure of the sensing device **602** against the skin of the user **608** has dropped below some predetermined threshold, wherein blood pressure measurements made when the applanation pressure is below that threshold are unlikely to be accurate. In response to this detection, the adjustment mechanism may move the sensing device **602** so that the applanation pressure increases. Similarly, the pressure sensor **604** may detect that the applanation pressure has risen above a second predetermined threshold, wherein the wearable tonometer **600** is likely to cause discomfort when the applanation pressure is above that threshold. In response to this detection, the adjustment mechanism may move the sensing device **602** so that the applanation pressure decreases.

[0038] According to other embodiments not depicted, the wearable tonometer may include biasing members configured to move the sensing device in a plane tangent to the skin of the user or along the axis normal to that plane, but not include electromagnetic actuators. In such embodiments, the biasing members would have one end fixed in place in the sensing device and one end fixed in place in the band.

[0039] FIG. **7** shows an embodiment of a wearable tonometer **700** similar to that of FIG. **6**, except that the adjustment mechanism includes screw members **714**A, **714**B, and **714**C in place of biasing members. Although three screw members are depicted, other numbers of screw members may be used. The screw members **714**A, **714**B, and **714**C are configured to be turned by micromotors **716**A, **716**B, and **716**C respectively in order to adjust the position of a sensing device **702** relative to a hand **712**. Adjusting the position of the sensing device **702** relative to the band **712** may include moving the sensing device **702** in a plane tangent to the skin of the user **708** or along the axis normal to that plane. By adjusting the position of the sensing device **702** relative to the band **712**, the adjustment mechanism may move the sensing device **70** so that the resiliently deformable pad-cap structure **710** remains in contact with skin proximate a surface artery **706** of the user **708**.

[0040] The adjustment mechanism may be configured to adjust an applanation pressure of the sensing device **702** against the skin of the user **708**. As in the embodiment of FIG. **6**, the adjustment mechanism of the wearable tonometer **700** of FIG. **7** may be configured to receive a starting signal indicating a beginning of a blood pressure measurement. In response to receiving the starting signal, the adjustment mechanism may increase the applanation pressure of the sensing device **702** against the skin of the user **708**. The applanation pressure may be increased by turning at least one screw member using its micromotor. The adjustment mechanism may be further configured to receive an ending signal indicating an ending of the blood pressure measurement. In response to receiving the ending signal, the adjustment mechanism may be configured to decrease the applanation pressure of the sensing device **702** against the skin of the user **708**.

[0041] The adjustment mechanism may be further configured to adjust the applanation pressure of the sensing device **702** against the skin of the user **708** based at least in part on a pressure measurement made by the pressure sensor **704**. When the pressure measurement drops below some predetermined threshold, at least one micromotor may move at least one screw member so as to increase the applanation pressure, and when the pressure measurement rises above below some predetermined threshold, at least one micromotor may move at least one screw member so as to decrease the applanation pressure.

[0042] Another embodiment of the present disclosure is shown in FIG. **8**. According to the embodiment depicted in FIG. **8**, a wearable tonometer **800** is provided, including a sensing device **802**. The sensing device **802** includes a pressure sensor **804** configured to measure a pulse pressure wave of blood pressure in an artery **806** of a user **808**. The sensing device **802** further includes a resiliently deformable pad-cap structure **810** positioned between the pressure sensor **804** and skin of the user **808** proximate the artery **806**. The wearable tonometer **800** also includes a band **812** that holds the sensing device **802** in contact with the skin of the user **808**.

[0043] In the embodiment of FIG. **8**, the pressure sensor **804** is coupled to a pressurized fluid **814** contained within the sensing device **802**. The pressurized fluid **814** may be air, or may be some other fluid. When pressure is exerted on the sensing device **802**, the pressurized fluid **814** exerts pressure in the opposite direction on the sensing device **802**. The pressurized fluid **814** functions similarly to the biasing members **614**A, **614**B, and **614**C in the embodiment of FIG. **6**, in that it exerts a force on the sensing device **802** in a direction opposite that of a displacement from an equilibrium position. The pressurized fluid **814** may thus adjust applanation pressure of the sensing device **802** against the skin of the user **808**.

[0044] FIG. **9** shows another embodiment of the present disclosure. In FIG. **9**, a wearable tonometer **900** is shown, including a sensing device **902**. The wearable tonometer **900** further includes a cantilever **904** that is coupled on one end to the sensing device **902** and coupled on another end to a band **906**. The cantilever **904** may be configured to move the sensing device **902** relative to the band **906** so that it is in contact with skin proximate an artery **908** of a user **910**. The wearable tonometer **900** also includes a screw member **912** configured to move the cantilever **904**, and a micromotor **914** configured to turn the screw member **912**. Although the embodiment depicted in FIG. **9** only includes one screw member **912** and one micromotor **914**, other numbers of screw members and micromotors may be used in other embodiments.

[0045] The micromotor **914** may be configured to move the cantilever **904** in a plane tangent to the skin of the user **910** while the position of the band **906** remains fixed, and/or in a plane perpendicular to that plane and parallel to the artery **908** of the user **910**. The cantilever **904** may be dynamically moved in the plane tangent to the skin of the user **910** so that the sensing device **902** is in contact with the skin covering the artery **908** of the user **910**.

[0046] According to another embodiment of the present disclosure, shown in FIG. **10**, a wearable tonometer **1000** is provided, comprising a first sensing device **1002**. The first sensing device **1002** includes a first pressure sensor **1004** configured to measure a pulse pressure wave of blood pressure in an artery **1006** of a user **1008**. In the embodiment depicted in FIG. **10**, the artery **1006** is a radial artery and the first sensing device **1002** sits between the radius **1010** and flexor carpi radialis tendon **1012** of the user **1008**. The wearable tonometer **1000** may additionally or instead be configured to measure a pulse pressure wave of blood pressure in other arteries of the user **1008**.

[0047] The first sensing device **1002** further includes a first resiliently deformable pad-cap structure **1014** positioned between the first pressure sensor **1004** and skin of the user **1008** proximate the artery **1006**. The first resiliently deformable pad-cap structure **1014** is configured to apply an applanation pressure to the skin proximate the artery **1006** of the user **1008**.

[0048] In addition, the first resiliently deformable pad-cap structure **1014** is configured to protect the first pressure sensor **1004** from damage. The first resiliently deformable pad-cap structure **1014** may consist of cloth, them, an elastomeric material, or some other resiliently deformable, material. or combination of materials. The wearable tonometer **1000** further includes a band **1016** that is configured to hold the first sensing device **1002** in contact with the skin of the user **1008**.

[0049] The wearable tonometer **1000** of FIG. **10** further includes a second resiliently deformable pad-cap structure **1018** adjacent to skin of the user **1008**. The use of a second resiliently deformable pad-cap structure **1018** as well as a first resiliently deformable pad-cap structure **1014** allows the applanation pressure exerted by the wearable tonometer **1000** on the skin of the user **1008** to be distributed over a larger surface. The second resiliently deformable pad-cap structure **1018** may also provide additional stability for the first sensing device **1002** to help keep it in place.

[0050] The second resiliently deformable pad-cap structure **1018** may be included in a second sensing device **1020**. The second sensing device **1020** may include a second pressure sensor **1022** configured to measure a pulse pressure wave of blood pressure in an artery **1024** of the user **1008**. In the embodiment depicted in FIG. **10**, the artery for which the second pressure sensor **1022** is configured to measure a pulse pressure wave of blood pressure is an ulnar artery, while the first pressure sensor **1004** is configured to measure a pulse pressure wave of blood pressure in the radial artery. In other embodiments, the first pressure sensor **1004** and the second pressure sensor **1022** may be configured to measure pulse pressure waves of blood pressure in the same artery.

[0051] The wearable tonometer **1000** may be configured to determine whether the pulse pressure wave signal from the first pressure sensor **1004** or the second pressure sensor **1022** is higher in quality, based on, for example, noise in each of the measurements. The wearable tonometer **1000** may also be configured to average the signals from the pressure sensors, or to perform other operations that take the first and second pressure measurements as inputs and produce some output.

[0052] The wearable tonometer **1000** further includes a solid plate **1026** attached to the first resiliently deformable pad-cap structure **1014**, the second resiliently deformable pad-cap structure **1018**, and the band **1016**. In the embodiment of FIG. **10**, the solid plate **1026** bridges the flexor carpi radialis tendon **1012** of the user **1008**, thus allowing the first sensing device **1002** and the second sensing device **1020** to remain in place relative to the skin of the user **1008** while the flexor carpi radialis tendon **1012** of the user **1008** moves. In other embodiments, the solid plate **1026** may bridge other tendons and allow those tendons to move while keeping the sensing devices in place.

[0053] FIG. **11** schematically shows a form-agnostic sensory and logic system **1100** for use with a wearable tonometer. The sensory and logic system **1100** includes a sensor suite **1102** operatively coupled to a computing system **1104**. The computing system **1104** includes a logic machine **1106** and a data-storage machine **1108**. The computing system **1104** is operatively coupled to a display subsystem **1110**, a communication subsystem **1112**, an input subsystem **1114**, and/or other components not shown in FIG. **11**.

[0054] Logic machine **1106** includes one or more physical devices configured to execute instructions. The logic machine **1106** may be configured to execute instructions that are part of one or more applications, services, programs, routines, libraries, objects, components, data structures, or other logical constructs. Such instructions may be implemented to perform a task, implement a data type, transform the state of one or more components, achieve a technical effect, or otherwise arrive at a desired result.

[0055] Logic machine **1106** may include one or more processors configured to execute software instructions. Additionally or alternatively, the logic machine **1106** may include one re hardware or firmware logic machines configured to execute hardware or firmware instructions. Processors of the logic machine **1106** may be single-core or multi-core, and the instructions executed thereon may be configured for sequential, parallel, and/or distributed processing. Individual components of a logic machine optionally may be distributed among two or more separate devices, which may be remotely located and/or configured for coordinated processing. Aspects of a logic machine may be virtualized and executed by remotely accessible, networked computing devices in a cloud-computing configuration.

[0056] Data-storage machine **1108** includes one or more physical devices configured to hold instructions executable by logic machine **1106** to implement the methods and processes described herein. When such methods and processes are implemented, the state of the data-storage machine **1108** may be transformed to hold different data. The data-storage machine **1108** may include removable and/or built-in devices; it may include optical memory (e.g., CD, DVD HD-DVD, Blu-Ray Disc, etc.), semiconductor memory (e.g., RAM, EPROM, EEPROM, etc.), and/or magnetic memory hard-disk drive, floppy-disk drive, tape drive, MRAM, etc.), among others. The data-storage machine **1108** may include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, location-addressable, file-addressable, and/or content-addressable devices.

[0057] Data-storage machine **1108** includes one more physical devices. However, aspects of the instructions described herein alternatively may be propagated by a communication medium (e.g., an electromagnetic signal, an optical signal, etc.) that is not held by a physical device for a finite duration.

[0058] Aspects of logic machine **1106** and data-storage machine **1108** may be integrated together into one or more hardware-logic components. Such hardware-logic components may include field-programmable gate arrays (FPGAs), program- and application-specific integrated circuits (PASIC/ASICs), program- and application-specific standard products (PSSP/ASSPs), system-on-a-chip (SOC), and complex programmable logic devices (CPLDs), for example.

[0059] Display subsystem **1110** may be used to present a visual representation of data held by data-storage machine **1108**. This visual representation may take the form of a graphical user interface (GUI). As the herein described methods and processes change the data held by the data-storage machine **1108**, and thus transform the state of the data-storage machine, **1108**, the state of display subsystem **1110** may likewise be transformed to visually represent changes in the underlying data. Display subsystem **1110** may include one or more display subsystem devices utilizing virtually any type of technology. Such display subsystem devices may be combined with logic machine **1106** and/or data-storage machine **1108** in a shared enclosure ,or such display subsystem devices may be peripheral display subsystem devices.

[0060] Communication subsystem **1112** may be configured to communicatively couple computing system **1104** to one or more other computing devices. The communication subsystem **1112** may include wired and/or wireless communication devices compatible with one or more different communication protocols. As non-limiting examples, the communication subsystem **1112** may be configured for communication via a wireless telephone network, a local- or wide-area network, and/or the Internet.

[0061] Input subsystem **1114** may comprise or interface with one or more user-input devices such as a keyboard, touch screen, button, dial, joystick, or switch. In some embodiments, the input subsystem **1114** may comprise or interface with selected natural user input (NUI) componentry. Such componentry may be integrated or peripheral, and the transduction and/or processing of input actions may be handled on- or off-board. Example NUI componentry may include a microphone for speech and/or voice recognition; an infrared, color, stereoscopic, and/or depth camera for machine vision and/or gesture recognition; a head tracker, eye tracker, accelerometer, and/or gyroscope for motion detection and/or intent recognition.

[0062] Sensor suite **1102** may include one or more different sensors for example, radial tonometry sensor **1118**, a touch-screen sensor, push-button sensor, microphone, visible-light sensor, ultraviolet sensor, ambient-temperature sensor, contact sensors, and/or GPS receiver as described above with reference to FIG. **1**. Sensor suite **1102** may include motion sensor suite **1116**. Motion sensor suite **1116** may include one or more of an accelerometer, gyroscope, magnetometer, or other suitable motion detectors.

[0063] As described herein, radial tonometry sensor **1118** may include pressure transducer **1120**. Computing system **1104** may include radial tonometry sensor control subsystem **1122**, which may be communicatively coupled to logic machine **1106** and data-storage machine **1108**. Pressure transducer **1120** may comprise one or more piezo-resistive sensors configured to provide absolute pressure signals to computing system **1104** via an analog-to-digital converter. Pressure transducer **1120** may be configured to transduce pressure waves from the artery **1124** through the skin **1126** of the user.

[0064] Radial tonometry sensor control subsystem **1122** may further process the raw signals to determine heart rate, blood pressure, caloric expenditures, etc. Processed signals may be stored and output via computing system **1104**. Control signals sent to radial tonometry sensor **1118** may be based on signals received from pressure transducer **1120**, signals derived from sensor suite **1102**, information stored in data-storage machine **1108**, input received from communication subsystem **1112**, input received from input subsystem **1114**, etc.

[0065] The following paragraphs provide additional support for the claims of the subject application. According to one aspect of the present disclosure, a wearable tonometer is provided, comprising a sensing device. The sensing device may include a pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user. The sensing device may further include a resiliently deformable pad positioned on a sensing surface side of the pressure sensor and configured to contact skin of the user proximate the artery. The sensing device may further include a rigid internal structure positioned at least partially within the resiliently deformable pad and configured to transmit the pulse pressure wave on its way to the pressure sensor. The wearable tonometer may further include a band that holds the sensing device in contact with the skin of the user.

[0066] According to this aspect, the wearable tonometer may further include a plunger structure coupled to the rigid internal structure. The pressure sensor may be directly or indirectly coupled to the plunger structure on a side of the plunger structure opposite the rigid internal structure.

[0067] According to this aspect, the plunger structure may be coupled directly to the pressure sensor.

[0068] According to this aspect, the resiliently deformable pad may cover the rigid internal structure at least on a side of the rigid internal structure opposite the plunger structure.

[0069] According to this aspect, the plunger structure may be oriented along an axis normal to a plane tangent to a skin contacting surface of the resiliently deformable pad at a point of contact with the skin of the user.

[0070] According to this aspect, the pressure sensor may be coupled to a pressurized fluid contained within the sensing device.

[0071] According to this aspect, the rigid internal structure may be prestressed by the resiliently deformable pad and may apply a baseline pressure to the pressure sensor.

[0072] According to this aspect, the resiliently deformable pad may cover the entire sensing device.

[0073] According to this aspect, the resiliently deformable pad may have a convex skin-contacting surface that is elongated along a longitudinal axis.

[0074] According to this aspect, the rigid internal structure may have a plate-like shape that is elongated along the longitudinal axis.

[0075] According to another aspect of the present disclosure, a wearable tonometer is provided, comprising a sensing device. The sensing device may include a pressure sensor configured to measure a pulse pressure wave of blood pressure in au artery of a user. The sensing device may further include a resiliently deformable pad-cap structure positioned between the pressure sensor and skin of the user proximate the artery. The wearable tonometer may further include a band that may hold the sensing device in contact with the skin of the user. The wearable tonometer may further include an adjustment mechanism configured to move the sensing device relative to the band. The adjustment mechanism may be configured to move the sensing device in a plane tangent to the skin of the user while the position of the band remains fixed.

[0076] According to this aspect, the adjustment mechanism may be further configured to adjust an applanation pressure of the sensing device against the skin of the user.

[0077] According to this aspect, the adjustment mechanism may be further configured to receive a starting signal indicating a beginning of a blood pressure measurement. In response to receiving the starting the adjustment mechanism may be configured to increase the applanation pressure of the sensing device against the skin of the user. The adjustment mechanism may be further configured to receive an ending signal indicating an ending of the blood pressure measurement. In response to receiving the ending signal, the adjustment mechanism may be configured to decrease the applanation pressure of the sensing device against the skin of the user.

[0078] According to this aspect, the adjustment mechanism may be configured to adjust the applanation pressure of the sensing device against the skin of the user based at least in part on a pressure measurement made by the pressure sensor.

[0079] According to this aspect, the sensing device may be dynamically moved in a plane tangent to the skin of the user so that the sensing device is in contact with the skin covering a surface artery of the user.

[0080] According to this aspect, the adjustment mechanism may include a biasing member or screw member.

[0081] According to this aspect, the pressure sensor may be coupled to a pressurized fluid contained within the sensing device.

[0082] According to this aspect, the adjustment mechanism may include a cantilever that is coupled on one end to the sensing device and coupled on another end to the hand

[0083] According to another aspect of the present disclosure, a wearable tonometer is provided, comprising a first sensing device. The first sensing device may include a first pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user. The first sensing device may further include a first resiliently deformable pad-cap structure positioned between the first pressure sensor and skin of the user proximate the artery. The wearable tonometer may further include a band that holds the first sensing device in contact with the skin of the user. The wearable tonometer may further include a second resiliently deformable pad-cap structure adjacent to skin of the user. The wearable tonometer may further include a solid plate attached to the first resiliently deformable pad-cap structure, the second resiliently deformable pad-cap structure, and the band.

[0084] According to this aspect, the wearable tonometer may further include a second sensing device, wherein the second sensing device includes a second pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of the user. The wearable tonometer may further include the second resiliently deformable pad-cap structure.

[0085] It will be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific embodiments or examples are not to be considered in a limiting sense, because numerous variations are possible. The specific routines or methods described herein may represent one or more of any number of processing strategies. As such, various acts illustrated and/or described may be performed in the sequence illustrated and/or described, in other sequences, in parallel, or omitted. Likewise, the order of the above-described processes may be changed.

[0086] The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

1. A wearable tonometer, comprising:
a sensing device, wherein the sensing device includes:
a pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user;
a resiliently deformable pad positioned on a sensing surface side of the pressure sensor and configured to contact skin of the user proximate the artery;
a rigid internal structure positioned at least partially within the resiliently deformable pad and configured to transmit the pulse pressure wave on its way to the pressure sensor; and
a band that holds the sensing device in contact with the skin of the user.

2. The wearable tonometer of claim 1, further comprising a plunger structure coupled to the rigid internal structure, wherein the pressure sensor is directly or indirectly coupled to the plunger structure on a side of the plunger structure opposite the rigid internal structure.

3. The wearable tonometer of claim **2**, wherein the plunger structure is coupled directly to the pressure sensor.

4. The wearable tonometer of claim **2**, wherein the resiliently deformable pad covers the rigid internal structure at least on a side of the rigid internal structure opposite the plunger structure.

5. The wearable tonometer of claim **2**, wherein the plunger structure is oriented along an axis normal to a plane tangent to a skin contacting surface of the resiliently deformable pad at a point of contact with the skin of the user.

6. The wearable tonometer of claim **1**, wherein the pressure sensor is coupled to a pressurized fluid contained within the sensing device.

7. The wearable tonometer of claim **1**, wherein the rigid internal structure is prestressed by the resiliently deformable pad and applies a baseline pressure to the pressure sensor.

8. The wearable tonometer of claim **1**, wherein the resiliently deformable pad covers the entire sensing device.

9. The wearable tonometer of claim **1**, wherein the resiliently deformable pad has a convex skin-contacting surface that is elongated along longitudinal axis.

10. The wearable tonometer of claim **9**, wherein the rigid structure has a plate-like shape that is elongated along the longitudinal axis.

11. A wearable tonometer, comprising:

a sensing device, wherein the sensing device includes:

a pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user; and

a resiliently deformable pad-cap structure positioned between the pressure sensor and skin of the user proximate the artery;

a band that holds the sensing device in contact with the skin of the user; and

an adjustment mechanism configured to move the sensing device relative to the band, wherein the adjustment mechanism is configured to move the sensing device in a plane tangent to the skit of the user while the position of the band remains fixed.

12. The wearable tonometer of claim **11**, wherein the adjustment mechanism is further configured to adjust an applanation pressure of the sensing device against the skin of the user.

13. The wearable tonometer of claim **12**, wherein the adjustment mechanism is further configured to:

receive a starting signal indicating a beginning of a blood pressure measurement;

in response to receiving the starting signal, increase the applanation pressure of the sensing device against the skin of the user;

receive an ending signal indicating an ending of the blood pressure measurement; and

in response to receiving the ending signal, decrease the applanation pressure of the sensing device against the skin of the user.

14. The wearable tonometer of claim **12**, wherein the adjustment mechanism is configured to adjust the applanation pressure of the sensing device against the skin of the user based at least in part on a pressure measurement made by the pressure sensor.

15. The wearable tonometer claim **11**, wherein the sensing device is dynamically moved in a plane tangent to the skin of the user so that the sensing device is in contact with the skin covering a surface artery of the user.

16. The wearable tonometer of claim **11**, wherein the adjustment mechanism includes a biasing member or screw member.

17. The wearable tonometer of claim **11**, wherein the pressure sensor is coupled to a pressurized fluid contained within the sensing device.

18. The wearable tonometer of claim **11**, wherein the adjustment mechanism includes a cantilever that is coupled on one end to the sensing device and coupled on another end to the band.

19. A wearable tonometer, comprising:

a first sensing device, wherein the first sensing device includes:

first pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of a user;

a first resiliently deformable pad-cap structure positioned between the first pressure sensor and skin of the user proximate the artery;

a band that holds the first sensing device in contact with the skin of the user;

a second resiliently deformable pad-cap structure adjacent to skin of the user; and

a solid plate attached to the first resiliently deformable pad-cap structure, the second resiliently deformable pad-cap structure, and the band.

20. The wearable tonometer of claim **19**, further comprising a second sensing device, wherein the second sensing device includes:

a second pressure sensor configured to measure a pulse pressure wave of blood pressure in an artery of the user; and

the second resiliently deformable pad-cap structure.

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摘要(译)

提供了一种可穿戴眼压计，包括传感装置。传感装置可包括压力传感器，其配置成测量用户动脉中的脉压波。传感装置可以包括可弹性变形的垫或垫帽结构，其定位在压力传感器的传感表面侧上并且被配置为接触靠近动脉的使用者的皮肤。可佩戴眼压计可包括保持感测装置与皮肤接触的带。在一些实施例中，感测装置可包括刚性内部结构，其配置成传输脉冲压力波。在一些实施例中，可佩戴眼压计可包括调节机构，该调节机构构造成相对于带移动感测装置。在一些实施例中，可佩戴眼压计可包括第二可弹性变形的垫帽结构，以及附接到可弹性变形的垫帽结构和带的实心板。