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(54) APPARATUS FOR DETERMINING A BLOOD PRESSURE MEASUREMENT

(57) There is provided an apparatus (100) for determining a blood pressure measurement for a subject (102). The apparatus (100) comprises a processor (104) configured to acquire, from a light sensor (106), measurements of an intensity of light (108) of a first wavelength range reflected from the skin (110) of the subject (102) and an intensity of light (112) of a second wavelength range reflected from the skin (110) of the subject (102) for a range of forces at which the light sensor (106) is applied to the skin (110). The processor (104) is also configured to determine a ratio of the intensity of light (108) of the first wavelength range to the intensity of light (112) of the second wavelength range for each of the applied forces and determine a blood pressure measurement for the subject (102) based on an integral of the ratios with respect to the applied forces.

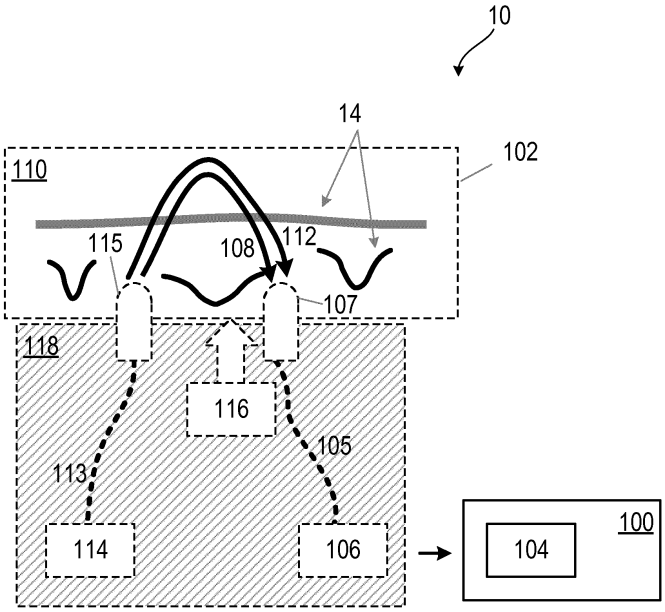

Fig. 1

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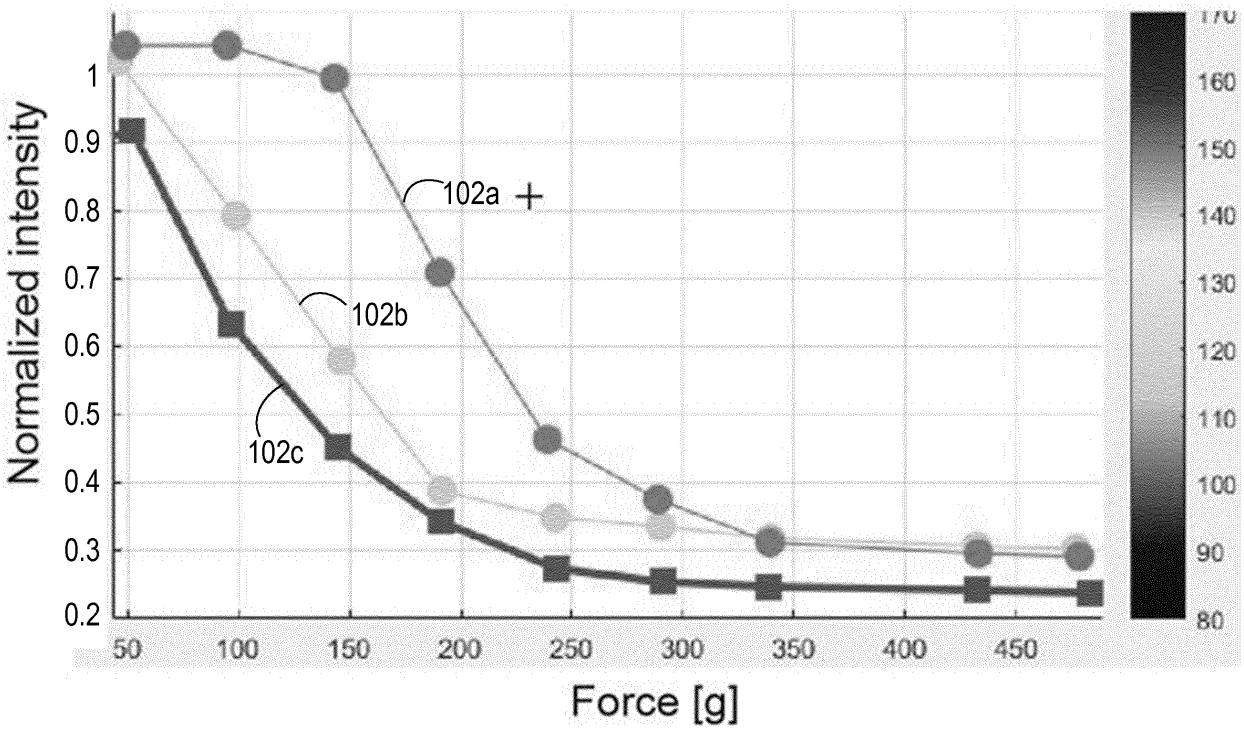
Normalized intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
50
100
150
200
250
300
350
400
450
Force [g]
102a
102b
102c
170
160
150
140
130
120
110
100
90
80

Fig. 5

Description

FIELD OF THE INVENTION

[0001] The disclosure relates to an apparatus and method for determining a blood pressure measurement for a subject.

BACKGROUND OF THE INVENTION

[0002] Blood pressure is considered to be one of the most important physiological parameters for monitoring subjects. This is especially the case for subjects in a critical condition. Blood pressure can, for example, provide a useful indication of the physical or physiological condition of a subject. A variety of techniques exist for measuring blood pressure. The techniques can be divided into two categories, namely invasive techniques and non-invasive techniques. Most invasive techniques are expensive and are generally only used in hospitals (especially in intensive care units) as they require specialists for operation. Therefore, non-invasive techniques can be more practical where blood pressure measurements need to be acquired more frequently by an untrained user.

[0003] The most common non-invasive technique for measuring the blood pressure of a subject is with the aid of a wearable cuff on the finger, wrist or upper arm of the subject, which is inflated above the systolic blood pressure. The non-invasive techniques require the wearable cuff to be inflated and then the blood pressure measurement is determined based on changes in sound, pressure and optics upon deflation of the wearable cuff. An example of such a technique involves inflating a wearable cuff around a finger of the subject and monitoring a single infrared photoplethysmogram (PPG) signal. In a variation of this technique, an air pressure signal may instead be monitored. The signal that is monitored in these techniques is then used to determine a blood pressure measurement. Other non-invasive techniques for measuring the blood pressure of a subject do not require the use of a wearable cuff. An example of such a non-invasive technique involves measuring a pulse wave velocity (PWV), which is the speed at which blood passes over several locations of the circulatory system of the body of the subject, and measuring a pulse transit time delay, which is based on a correlation between electrical signals, such as electrocardiogram (ECG) signals, and optical signals, such as photoplethysmogram (PPG) signals.

[0004] There also exist non-invasive techniques that use a spectral measurement of the skin/tissue combined with applied pressure. JP 2005/131356 discloses an example of a blood pressure measuring device that uses such a technique. The device has a body installed on the skin of a subject, where the body has two light emitting elements for irradiating light having a predetermined wavelength toward an artery in the skin of the subject, two light receiving elements for receiving a pulse wave generated by reflected light in the downstream side of the device, and a pressure pulse wave sensor pressing the skin of the subject so that pressure can be varied. A maximum blood pressure value is determined on the basis of the fact that signal intensity detected by the light receiving elements exceeds a predetermined criterion value by continuously reducing pressing force of the pressure pulse wave sensor from pressure higher than the maximum blood pressure value.

[0005] However, it is challenging to measure blood pressure continuously using a non-invasive technique and, at present, there is no device with proven accuracy and reliability that can measure blood pressure in a continuous and non-invasive way.

SUMMARY OF THE INVENTION

[0006] As noted above, a limitation with existing apparatus and methods for determining a blood pressure measurement for a subject is that they are not able to accurately and reliably measure blood pressure in a continuous and non-invasive way. It would thus be valuable to have an improved apparatus and method for determining a blood pressure measurement for a subject, which addresses the existing problems.

[0007] Therefore, according to a first aspect, there is provided an apparatus for determining a blood pressure measurement for a subject. The apparatus comprises a processor configured to acquire, from a light sensor, measurements of an intensity of light of a first wavelength range reflected from the skin of the subject and an intensity of light of a second wavelength range reflected from the skin of the subject for a range of forces at which the light sensor is applied to the skin of the subject. The processor is also configured to, for each of the applied forces, determine a ratio of the intensity of light of the first wavelength range to the intensity of light of the second wavelength range and determine a blood pressure measurement for the subject based on an integral of the ratios with respect to the applied forces.

[0008] In some embodiments, the second wavelength range may be different to the first wavelength range. In some embodiments, the first wavelength range may be a red wavelength range or an infrared wavelength range. In some embodiments, the second wavelength range may be a green wavelength range.

[0009] In some embodiments, the processor may be further configured to plot the determined ratio of the intensity of light of the first wavelength range to the intensity of light of the second wavelength range as a function of the range of forces at which the light sensor is applied to the skin of the subject. In some embodiments, the integral of the ratios with respect to the applied forces may comprise the area under the plot.

[0010] According to a second aspect, there is provided a system for determining a blood pressure measurement for a subject. The system comprises the apparatus as described above and the light sensor. The light sensor is configured to acquire measurements of the intensity

of light of the first wavelength range reflected from the skin of the subject and the intensity of light of the second wavelength range reflected from the skin of the subject for the range of forces at which the light sensor is applied to the skin of the subject.

[0011] In some embodiments, the system may further comprise a force sensor configured to measure the range of forces at which the light sensor is applied to the skin of the subject.

[0012] In some embodiments, the system may further comprise a light source configured to emit light of the first wavelength range and light of the second wavelength range at the skin of the subject.

[0013] In some embodiments, the system may further comprise an optical head contactable with the skin of the subject. In some embodiments, the optical head may comprise the light sensor. In some embodiments, the optical head may further comprise the light source.

[0014] According to a third aspect, there is provided a method for determining a blood pressure measurement for a subject. The method comprises acquiring, from a light sensor, measurements of an intensity of light of a first wavelength range reflected from the skin of the subject and an intensity of light of a second wavelength range reflected from the skin of the subject for a range of forces at which the light sensor is applied to the skin of the subject. The method also comprises, for each of the applied forces, determining a ratio of the intensity of light of the first wavelength range to the intensity of light of the second wavelength range and determining a blood pressure measurement for the subject based on an integral of the ratios with respect to the applied forces.

[0015] According to a fourth aspect, there is provided a computer program product comprising a computer readable medium, the computer readable medium having computer readable code embodied therein, the computer readable code being configured such that, on execution by a suitable computer or processor, the computer or processor is caused to perform the method described above.

[0016] According to the aspects and embodiments described above, the limitations of existing systems are addressed. In particular, according to the above-described aspects and embodiments, it is possible to accurately and reliably measure blood pressure in a continuous and non-invasive way. This is possible by relying on the applied force and taking advantage of the fact that the applied force is known. In this way, according to the above-described aspects and embodiments, not only the optical properties of blood can be measured (such as in the pulse wave velocity technique), but it is also possible to measure the mechanical properties of the blood, as blood pressure is ultimately a mechanical property. The above-described aspects and embodiments are also more comfortable for the subject than the existing techniques that require a wearable cuff to be inflated around a part of the body of the subject. There is thus provided an improved apparatus and method for determining a blood pressure measurement for a subject that overcome the existing problems.

[0017] These and other aspects will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Exemplary embodiments will now be described, by way of example only, with reference to the following drawings, in which:

Fig. 1 is a schematic illustration of an apparatus for determining a blood pressure measurement for a subject in use in a system according to an embodiment;

Fig. 2 is a schematic illustration of an apparatus for determining a blood pressure measurement for a subject in use in a system according to another embodiment;

Fig. 3 is a schematic illustration of a system in use for determining a blood pressure measurement for a subject according to an embodiment;

Fig. 4 is a flow chart illustrating a method for determining a blood pressure measurement for a subject according to an embodiment;

Fig. 5 is an illustration of measurements of an intensity of light reflected from the skin of a subject for a range of forces at which a light sensor is applied to the skin of the subject according to an embodiment; and

Figs. 6A-B are illustrations of blood pressure measurements determined for a subject using an existing technique and using an apparatus described herein compared to reference blood pressure measurements according to an embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0019] As noted above, there is provided herein an improved apparatus and method for determining a blood pressure measurement for a subject, which overcomes existing problems. The subject referred to herein can, for example, be a patient or any other subject.

[0020] Figs. 1 and 2 illustrate an apparatus 100 for determining a blood pressure measurement for a subject 102 according to an embodiment. As illustrated in Figs. 1 and 2, the apparatus 100 comprises a processor 104. Briefly, the processor 104 of the apparatus 100 is configured to acquire, from a light sensor (or light detector) 106, measurements of an intensity of light 108 of a first wavelength range reflected from the skin 110 of the subject 102 and an intensity of light 112 of a second wavelength range reflected from the skin 110 of the subject 102 for a range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. The light sensor 106 may form a part of a load unit (not shown), wherein said load unit can be arranged to apply a predefined force

within the range of forces to the subject. The load unit may be further coupled to the processor 104, which can be arranged to receive data of the applied force and also control the applied by the load unit (or light sensor 106) force. In other words, the processor 104 can be arranged to acquire from the light sensor measurements of an intensity of light and receive readings from the load unit (or the sensor 106) on the range of forces at which the light sensor is applied to the skin of the subject.

[0021] In more detail, light 108 of the first wavelength range and light 112 of the second wavelength range that enters the skin 110 of the subject 102 is reflected from one or more cells (e.g. blood cells) in the skin 110 of the subject 102. For example, as illustrated in Figs. 1 and 2, the light 108 of the first wavelength range and the light 112 of the second wavelength range may be reflected from one or more blood vessels 14 in the skin 110 of the subject 102. In effect, the light 108 of the first wavelength range and the light 112 of the second wavelength range can be reflected by the skin 110 and the blood containing tissue under the skin 110.

[0022] According to some embodiments, the second wavelength range can be different to the first wavelength range. In some embodiments, the first wavelength range may be a red wavelength range. Thus, the light 108 of the first wavelength range may comprise light 108 of a wavelength in a range from 620 nm to 700 nm according to some embodiments. In other embodiments, the first wavelength range may be an infrared wavelength range. Thus, the light 108 of the first wavelength range may comprise light 108 of a wavelength in a range from 700 nm to 1 mm according to some embodiments. In some embodiments, the second wavelength range can be a green wavelength range. Thus, the light 112 of the second wavelength range may comprise light 112 of a wavelength in a range from 495 nm to 570 nm according to some embodiments. The spectral response of the skin 110 exhibits large absorption in the green wavelength range. As such, the green wavelength range can provide optimal conditions for detecting variations in blood pressure.

[0023] The processor 104 of the apparatus 100 is configured to determine a ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range for each of the applied forces. The processor 104 of the apparatus 100 is also configured to determine a blood pressure measurement for the subject 102 based on an integral of the ratios with respect to the applied forces.

[0024] The processor 104 of the apparatus 100 can be implemented in numerous ways, with software and/or hardware, to perform the various functions described herein. In some embodiments, the processor 104 may comprise one or more processors, which can each be configured to perform individual or multiple steps of the method described herein. In particular implementations, the processor 104 can comprise a plurality of software and/or hardware modules, each configured to perform, or that are for performing, individual or multiple steps of the method described herein. The processor 104 may comprise one or more microprocessors, one or more multi-core processors and/or one or more digital signal processors (DSPs), one or more processing units, and/or one or more controllers (such as one or more microcontrollers) that may be configured or programmed (e.g. using software or computer program code) to perform the various functions described herein. The processor 104 may be implemented as a combination of dedicated hardware (e.g. amplifiers, preamplifiers, analog-to-digital convertors (ADCs) and/or digital-to-analog convertors (DACs)) to perform some functions and one or more processors (e.g. one or more programmed microprocessors, DSPs and associated circuitry) to perform other functions.

[0025] There is also provided a system for determining a blood pressure measurement for a subject 102. As illustrated in Figs. 1 and 2, the system 10, 20 can comprise the apparatus 100 that is described herein. The system 10, 20 can also comprise the light sensor 106. Although not illustrated in Figs. 1 or 2, in some embodiments, the apparatus 100 itself may comprise the light sensor 106. In other embodiments, such as that illustrated in Figs. 1 and 2, the light sensor 106 can instead be external to (i.e. separate to or remote from) the apparatus 100. For example, in some embodiments, the light sensor 106 may be a separate entity or part of another apparatus (e.g. a device). The light sensor 106 is configured for application to the skin 110 of the subject 102. The light sensor 106 may be applied directly to the skin 110 of the subject 102 or indirectly to the skin 110 of the subject 102 (e.g. via one or more other components, such as an optical fiber and/or an optical probe).

[0026] The light sensor 106 is configured to acquire the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102 and the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102 for the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. Thus, the light sensor 106 can be sensitive to light 108 of the first wavelength range and light 112 of the second wavelength range.

[0027] In some embodiments, as illustrated in Fig. 1 and Fig. 2, the light sensor 106 may comprise a single light sensor 106. In some of these embodiments, a single light sensor 106 may be configured to acquire both the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102 and the measurements of the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102. Thus, according to some embodiments, the light sensor 106 configured to acquire the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102 may be the same light sensor 106 as that configured to acquire the measurements of the intensity of light 112 of the second wavelength range reflected from

the skin 110 of the subject 102. For example, the light sensor 106 may be a multi-wavelength light sensor configured to acquire measurements of the intensity of light 108, 112 of at least two wavelength ranges reflected from the skin 110 of the subject 102.

[0028] In other embodiments, although not illustrated, the light sensor 106 may comprise at least two light sensors. In some of these embodiments, a light sensor other than the light sensor that is configured to acquire the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102 may be configured to acquire the measurements of the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102. Thus, according to some embodiments, different light sensors may be configured to acquire the measurements of the intensity of light 108, 112 of the different wavelength ranges.

[0029] Examples of a light sensor 106 that may be used to acquire the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102 and/or the measurements of the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102 include, but are not limited to a photodetector, a photodiode, a photomultiplier, or any other type of light sensor suitable to acquire measurements of the intensity of light 108, 112 of the first wavelength range and/or second wavelength range.

[0030] As illustrated in Figs. 1 and 2, according to some embodiments, the system 10, 20 can comprise a light source 114. The light source 114 may be configured to emit light 108 of the first wavelength range and light 112 of the second wavelength range at the skin 110 of the subject 102. That is, the light source 114 may be configured to emit the light 108 of the first wavelength range and the light 112 of the second wavelength range, which is subsequently reflected from the skin 110 of the subject 102. In some embodiments, the light source 114 may comprise a single light emitter that is configured to emit light 108, 112 of both the first wavelength range and the second wavelength range. In other embodiments, the light source 114 may comprise more than one light emitter, where at least one light emitter is configured to emit light 108 of the first wavelength range and at least one other light emitter is configured to emit light 112 of the second wavelength range.

[0031] In some of these embodiments, the at least one light emitter configured to emit light 108 of the first wavelength range and the at least one other light emitter configured to emit light 112 of the second wavelength range may be pulsated. For example, the at least one light emitter configured to emit light 108 of the first wavelength range may be operable to emit light at a different time to the at least one other light emitter configured to emit light 112 of the second wavelength range. In these embodiments, the light sensor 106 may be configured to synchronize the light pulses of the first wavelength range and the second wavelength range reflected from the skin 110 of the subject 102. In this way, a lower power consumption can be achieved and it is also possible to use only a single light sensor 106. In other embodiments, a light source (not illustrated) other than the light source 114 that is configured to emit the light 108 of the first wavelength range may be configured to emit the light 112 of the second wavelength range. Thus, in some embodiments, different light sources may be configured to emit the light 108, 112 of the different wavelength ranges.

[0032] Examples of a light source 114 (or a light emitter of a light source 114) that may be used to emit the light 108 of the first wavelength range and/or the light 112 of the second wavelength range include, but are not limited to a natural or ambient light source (or light emitter), as the sun, or any other natural or ambient light source (or light emitter), an artificial light source (or light emitter), such as a broadband light source (or light emitter), a light emitting diode (LED), a halogen lamp, an incandescent light bulb, or any other artificial light source (or light emitter), or any other light source (or light emitter), or any combination of light sources (or light emitters), suitable to emit light 108, 112 of the first wavelength range and/or second wavelength range. A natural or ambient light source (or light emitter) may be used to provide a less complex system and to ensure that less power is consumed. Fig. 1 illustrates a system 10 comprising an artificial light source 114, whereas Fig. 2 illustrates a system 20 comprising a natural light source 114. In some embodiments, the light source 114 (or light emitter of the light source 114) may be configured to emit white light comprising the light 108 of the first wavelength range and/or the light 112 of the second wavelength range. In other embodiments, the light source 114 (or light emitter of the light source 114) may be configured to emit only the light 108 of the first wavelength range and/or the light 112 of the second wavelength range, in the absence of light of any other wavelength ranges.

[0033] In some embodiments, such as that illustrated in Fig. 1, the light source 114 may be configured to emit light 108 of the first wavelength range and/or the light 112 of the second wavelength range via a first optical fiber 113 and a first optical probe 115. In these embodiments, the first optical probe 115 may be contactable with the skin 110 of the subject 102. Thus, in some embodiments, the first optical fiber 113 can be configured to transfer light 108 of the first wavelength range and/or the light 112 of the second wavelength range emitted by the light source 114 to the skin 110 of the subject 102, e.g. via the first optical probe 115.

[0034] Similarly, in some embodiments, such as that illustrated in Fig. 1, the light sensor 106 may be configured to acquire the measurements of the intensity of light 108 of the first wavelength range and/or the light 112 of the second wavelength range via a second optical fiber 105 and a second probe 107. In these embodiments, the second optical probe 107 may be contactable with the skin 110 of the subject 102. Thus, the light sensor 106 according to these embodiments is applied indirectly to

the skin 110 of the subject 102 via the second optical fiber 105 and a second probe 107. The second optical fiber 105 can be configured to transfer light 108 of the first wavelength range and/or the light 112 of the second wavelength range reflected from the skin 110 of the subject 102 to the light sensor 106, e.g. via the second optical probe 107.

[0035] In some embodiments, a distance between the light sensor 106 and the light source 114 may be a distance in a range from 1 to 10 mm, for example in a range from 1.5 to 9.5 mm, for example in a range from 2 to 9, for example in a range from 1.5 to 8.5 mm, for example in a range from 2 to 8 mm, for example in a range from 2.5 to 7.5 mm, for example in a range from 3 to 7 mm, for example in a range from 3.5 to 6.5 mm, for example in a range from 4 to 6 mm, for example in a range from 4.5 to 5.5 mm. For example, in some embodiments, the distance between the light sensor 106 and the light source 114 may be a distance selected from 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, or any non-integer distance between those values, or any other distance that is in the range from 1 to 10 mm. A distance between the light sensor 106 and the light source 114 that is less than or equal to 10 mm can ensure that the light reaching the light sensor 106 from the light source 114 has an intensity that is high enough for measurements of the intensity of light to be acquired, while a distance between the light sensor 106 and the light source 114 that is greater than or equal to 1 mm can ensure that the light emitted by the light source 114 penetrates the skin 110 of the subject 102 deep enough to obtain a reliable signal from larger blood vessels.

[0036] As illustrated in Fig. 1 and Fig. 2, according to some embodiments, the system 10, 20 may comprise a force sensor 116. The force sensor 116 can be configured (or arranged) to measure the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. Examples of a force sensor 116 that may be used to measure the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102 include, but are not limited to a pressure sensor, a capacitive sensor, a magnetic sensor, or any other type of force sensor suitable to measure the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. In some embodiments, the force sensor 116 can be arranged to measure the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102 by detecting a range of contact pressures at which the light sensor 106 is applied to the skin 110 of the subject 102.

[0037] In some embodiments, as illustrated in Fig. 1 and Fig. 2, the system 10, 20 can comprise an optical head 118. The optical head 118 may be contactable with the skin 110 of the subject 102 may include the load unit. In some embodiments, a device may comprise any one or more of the optical head 118, the light source 114, the first optical fiber 113, the first optical probe 115, the light sensor 106, the second optical fiber 105, the second optical probe 107, and the force sensor 116. In some embodiments where the system 10, 20 comprises an optical head 118, the optical head 118 can comprise any one or more of the light source 114, the first optical fiber 113, the first optical probe 115, the light sensor 106, the second optical fiber 105, the second optical probe 107, and the force sensor 116. In embodiments where the system 20 comprises a natural light source 114, such as that illustrated in Fig. 2, the optical head 118 can comprise an aperture or transparent window 120 through which light emitted from the light source 114 can pass to the skin 110 of the subject 102. The optical head 118 can minimize the effect of the interference from the environment on the measurements of the intensity of light. Examples of interference can, for example, include ambient light in the case of an artificial light source embodiments, air, or any other interference from the environment that may affect the measurements of the intensity of light.

[0038] As mentioned earlier, the optical head 118 is contactable with the skin 110 of the subject 102. In some embodiments, for example, the optical head 118 may be secured to or held in place on the skin 110 on a part of the body of the subject 102 in use. For example, in some embodiments, a surface of the optical head 118 may comprise an adhesive to secure or hold in place the optical head 118 to the skin 110 on a part of the body of the subject 102. In other embodiments, a band (or strap) 122 may comprise the optical head 118. The band 122 can be configured to be worn around (e.g. attached on) a part of the body of the subject 102 to secure or hold in place the optical head 118 on the skin 110 on the part of the body of the subject 102. For example, in some embodiments, the optical head 118 can be integrated into the band 122. In other embodiments, the optical head 118 may be placed under the band 122. Thus, the optical head 118 can be integrated into or placed under any object that is contactable with the skin 110 of the subject 102, such as a watch, a smartwatch, a headband, or any other object contactable with the skin 110 of the subject 102.

[0039] The optical head 118 may be secured to or held in place on the skin 110 on any part of the body of the subject 102. For example, in some embodiments, the part of the body of the subject 102 may be a peripheral site of the body of the subject 102, such as a wrist of the subject 102, a forearm of the subject 102, or any other peripheral site of the subject. In other embodiments, the part of the body of the subject 102 may be a central site of the body of the subject 102, such as the head (e.g. the forehead) of the subject 102, the chest of the subject 102, or any other central part of the body of the subject 102. A central site of the body of the subject 102 can, for example, provide more stable measurements of the intensity of light than a peripheral site of the body of the subject 102. In some embodiments, the part of the body of the subject 102 may be a part of the body of the subject 102 comprising a boney structure. In this way, the optical head 118 may be better supported when secured to or

held in place on the skin 110 on the part of the body of the subject 102. Also, complex skin deformations can be avoided and the measurements of the light intensity can be more accurate since there is less interference from the optical response of soft tissue, such as tendons, muscles, fat, or similar.

[0040] Fig. 3 illustrates an example optical head 118 in use according to an embodiment. The example optical head 118 comprises the light source 114 configured to emit the light 108 of the first wavelength range and the light 112 of the second wavelength range at the skin 110 of the subject 102. The example optical head 118 also comprises the light detector 106 configured to acquire measurements of the intensity of light 108 of the first wavelength range and the light 112 of the second wavelength range reflected from the skin 110 of the subject 102 for the range of forces at which the light sensor106 is applied to the skin 110 of the subject 102. In the illustrated example embodiment of Fig. 3, a band (or strap) 122 comprises the optical head 118. The band 122 is configured to be worn around a part of the body of the subject 102 to secure or hold in place the optical head 118 on the skin 110 on the part of the body of the subject 102. In the illustrated example embodiment of Fig. 3, the part of the body of the subject is the forearm (or, more specifically, the wrist) of the subject 102. However, as mentioned earlier, the optical head 118 may be secured to or held in place on the skin 110 on any other part of the body of the subject 102 in any other way.

[0041] Although not illustrated in Figs. 1, 2 or 3, in some embodiments, the apparatus 100 may comprise a communications interface (or communications circuitry). Alternatively or in addition, the communications interface may be external to (e.g. separate to or remote from) the apparatus 100. In some embodiments, the optical head 118 or a device comprising the optical head 118 may comprise the communications interface. The communications interface can be for enabling the apparatus 100, or components of the apparatus 100, to communicate with and/or connect to one or more other components, such as any of those described herein. For example, the communications interface can be for enabling the processor 104 of the apparatus 100 to communicate with and/or connect to any one or more of the light source 114, the light detector 106, the force sensor 116, and/or any other components. The communications interface may enable the apparatus 100, or components of the apparatus 100, to communicate and/or connect in any suitable way. For example, the communications interface may enable the apparatus 100, or components of the apparatus 100, to communicate and/or connect wirelessly, via a wired connection, or via any other communication (or data transfer) mechanism. In some wireless embodiments, for example, the communications interface may enable the apparatus 100, or components of the apparatus 100, to use radio frequency (RF), Bluetooth, or any other wireless communication technology to communicate and/or connect.

[0042] Although also not illustrated in Figs. 1, 2 or 3, in some embodiments, the apparatus 100 may comprise a memory. Alternatively or in addition, the memory may be external to (e.g. separate to or remote from) the apparatus 100. In some embodiments, the optical head 118 or a device comprising the optical head 118 may comprise the memory. The processor 104 of the apparatus 100 may be configured to communicate with and/or connect to the memory. The memory may comprise any type of non-transitory machine-readable medium, such as cache or system memory including volatile and non-volatile computer memory such as random access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), read-only memory (ROM), programmable ROM (PROM), erasable PROM (EPROM), and electrically erasable PROM (EEPROM). In some embodiments, the memory can be configured to store program code that can be executed by the processor 104 to cause the apparatus 100 to operate in the manner described herein.

[0043] Alternatively or in addition, in some embodiments, the memory can be configured to store information required by or resulting from the method described herein. For example, in some embodiments, the memory may be configured to store any one or more of the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102, the measurements of the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102, the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range, the determined blood pressure measurement for the subject 102, or any other information, or any combination of information, required by or resulting from the method described herein. In some embodiments, the processor 104 of the apparatus 100 can be configured to control the memory to store information required by or resulting from the method described herein.

[0044] Although also not illustrated in Figs. 1, 2 or 3, in some embodiments, the apparatus 100 may comprise a user interface. Alternatively or in addition, the user interface may be external to (e.g. separate to or remote from) the apparatus 100. In some embodiments, the optical head 118 or a device comprising the optical head 118 may comprise the user interface. The processor 104 of the apparatus 100 may be configured to communicate with and/or connect to a user interface. The user interface can be configured to render (e.g. output, display, or provide) information required by or resulting from the method described herein. For example, in some embodiments, the user interface may be configured to render (e.g. output, display, or provide) any one or more of the measurements of the intensity of light 108 of the first wavelength range reflected from the skin 110 of the subject 102, the measurements of the intensity of light 112 of the second wavelength range reflected from the skin 110 of the subject 102, the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of

the second wavelength range, the determined blood pressure measurement for the subject 102, or any other information, or any combination of information, required by or resulting from the method described herein. Alternatively or in addition, the user interface can be configured to receive a user input. For example, the user interface may allow a user to manually enter information or instructions, interact with and/or control the apparatus 100. Thus, the user interface may be any user interface that enables the rendering (or outputting, displaying, or providing) of information and, alternatively or in addition, enables a user to provide a user input. In some embodiments, the processor 104 of the apparatus 100 can be configured to control the user interface to operate in the manner described herein.

[0045] For example, the user interface may comprise one or more switches, one or more buttons, a keypad, a keyboard, a mouse, a touch screen or an application (e.g. on a smart device such as a tablet, a smartphone, or any other smart device), a display or display screen, a graphical user interface (GUI) such as a touch screen, or any other visual component, one or more speakers, one or more microphones or any other audio component, one or more lights (such as light emitting diode LED lights), a component for providing tactile or haptic feedback (such as a vibration function, or any other tactile feedback component), an augmented reality device (such as augmented reality glasses, or any other augmented reality device), a smart device (such as a smart mirror, a tablet, a smart phone, a smart watch, or any other smart device), or any other user interface, or combination of user interfaces. In some embodiments, the user interface that is controlled to render information may be the same user interface as that which enables the user to provide a user input.

[0046] Fig. 4 illustrates a method 200 for determining a blood pressure measurement for a subject 102 according to an embodiment. The method 200 may generally be performed by or under the control of the processor 104 of the apparatus 100. At block 202 of Fig. 4, measurements of an intensity of light 108 of a first wavelength range reflected from the skin 110 of the subject 102 and an intensity of light 112 of a second wavelength range reflected from the skin 110 of the subject 102 for a range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. The intensity of light 108 of the first wavelength range and the intensity of light 112 of a second wavelength range change as a function of the force at which the light sensor 106 is applied to the skin 110 of the subject 102. Thus, the intensity of light 108 of the first wavelength range and the intensity of light 112 of a second wavelength range are dependent on the force at which the light sensor 106 is applied to the skin 110 of the subject 102.

[0047] At block 204 of Fig. 4, for each of the applied forces, a ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range is determined. In some embodiments, the determined ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range may be normalized using the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range determined for the lowest applied force.

[0048] At block 206 of Fig. 4, a blood pressure measurement is determined for the subject 102 based on an integral of the ratios with respect to the applied forces. In some embodiments, blood pressure may be a function of a calibration constant (or calibration value) and the integral of the ratios with respect to the applied forces. Thus, in some embodiments, a calibration constant may be determined for use in converting the integral of the ratios with respect to the applied forces to a blood pressure measurement. In some embodiments, the calibration constant may be determined previously (e.g. in a calibration phase), such as through testing performed on a plurality of subjects to determine a correlation between blood pressure and the integral of the ratios with respect to the applied forces. Where the correlation is linear, the integral of the ratios with respect to the applied forces may be converted to a blood pressure measurement by multiplying the value of the integral of the ratios with respect to the applied forces by the calibration constant. The calibration constant may be stored in a memory, such as that mentioned earlier. Thus, according to some embodiments, the blood pressure *BP* measurement can be determined as follows:

$$BP = C \int_0^{F_{max}} \frac{I_1(F)}{I_2(F)} dF,$$

where C is a calibration constant, I_1 is the intensity of light 108 of the first wavelength range, I_2 is the intensity of light 112 of the second wavelength range, and F is the force at which the light sensor 106 is applied to the skin 110 of the subject 102. The calibration constant may, for example, be determined by large scale data analysis. In some embodiments, the calibration constant may be stored in a memory. As mentioned earlier, the apparatus 100 may comprise the memory according to some embodiments or the memory may be external to (i.e. separate to or remote from) the apparatus 100 according to other embodiments.

[0049] In some embodiments, the blood pressure measurement that is determined for the subject 102 based the integral of the ratios with respect to the applied forces may be a value for the systolic blood pressure. In embodiments where the ratios are normalized, the blood pressure measurement may be determined for the subject based on an integral of the normalized ratios with respect to the applied forces.

[0050] In some embodiments, the processor 104 of the further apparatus 100 may be configured to plot the determined ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second

wavelength range as a function of the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102. In these embodiments, the integral of the ratios with respect to the applied forces can comprise the area under the plot. Thus, according to these embodiments, the processor 104 can be configured to determine a blood pressure measurement for the subject 102 based on the area under the plot of the determined ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range as a function of the range of forces at which the light sensor 106 is applied to the skin 110 of the subject 102.

[0051] Fig. 5 is an example illustration of such a plot. In more detail, Fig. 5 is an illustration of the determined ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range for three different subjects 102a, 102b, 102c for a range of forces at which a light sensor 106 is applied to the skin 110 of those subjects 102a, 102b, 102c according to an embodiment. The vertical axis of Fig. 5 is the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range for three different subjects 102a, 102b, 102c for each of the subjects 102a, 102b, 102c. In this example illustration, the light 108 of the first wavelength range is of the infrared wavelength range at 800 nm and the light 112 of the second wavelength range is of the green wavelength range at 550 nm. The horizontal axis of Fig. 5 is the force at which the light sensor 106 is (or the load) applied to the skin 110 of the subjects 102a, 102b, 102c.

[0052] The effect of applying the light sensor 106 to the skin 110 of a subject 102 at a range of forces as described herein is that the skin 110 of the subject 102 appears whiter (or less red) in color as the force is increased. This is due to blood in the skin 110 of the subject 102 being removed from the skin 110 and tissue directly under the location at which the light sensor 106 is applied to the skin 110 of the subject 102. The pressure of the light sensor 106 on the skin 110 of the subject 102 causes the skin to appear whiter (or less red) in color. In spectroscopic terms, the intensity of light 108 of the first wavelength range and the intensity of light 112 of the second wavelength range increase when the force at which the light sensor 106 is applied to the skin 110 of a subject 102 is increased. However, the intensity of light 112 of the second wavelength range increases to a greater extent than the intensity of light 108 of the first wavelength range when the force at which the light sensor 106 is applied to the skin 110 of a subject 102 is increased. Thus, as illustrated in Fig. 5, the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range decreases when the force at which the light sensor 106 is applied to the skin 110 of a subject 102 is increased. This is due to the intensity of light 112 of the second wavelength range (which has the highest variations with increasing force compared to the intensity of light 108 of the first wavelength range) being in the denominator of the ratio.

[0053] The plot illustrated in Fig. 5 can be analyzed to determine the blood pressure measurement based on the area under the plot. For example, the area under each plot may be calculated by integration. This area under a plot directly correlates with blood pressure. If the correlation is linear, the area may be multiplied by a calibration constant to determine the blood pressure value measurement. The color of the line for each subject 102a, 102b, 102c provides an indication of their determined blood pressure based on the color chart shown on the right of Fig. 5. Thus, it can be seen that there is a correlation between the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range and the blood pressure of these subjects 102a, 102b, 102c. In particular, the higher the ratio of the intensity of light 108 of the first wavelength range to the intensity of light 112 of the second wavelength range, the higher the blood pressure.

[0054] Fig. 6A is an illustration of blood pressure measurements determined for a subject 102 using an existing technique (which are labelled as 602) compared to reference blood pressure measurements (which are labelled as 600). The existing technique is that which involves a wearable cuff inflated around a finger of the subject 102 where an infrared photoplethysmogram (PPG) signal is monitored to determine the blood pressure measurements. Fig. 6B is an illustration of blood pressure measurements determined for a subject 102 using the apparatus 100 and method 200 described earlier with reference to Fig. 4 according to an embodiment (which are labelled as 606) compared to reference blood pressure measurements (which are labelled as 604). More specifically, the blood pressure measurements of Fig. 6A and 6B are systolic blood pressure measurement. The reference blood pressure measurements can be acquired from any other technique, e.g. the previously mentioned technique that involves inflation of a wearable cuff around a part of the body of the subject to acquire blood pressure measurements.

[0055] As illustrated in Fig. 6A and Fig. 6B, overall, the blood pressure measurements 606 determined for a subject 102 using the apparatus 100 and method 200 described earlier with reference to Fig. 4 more closely match the reference blood pressure measurements 604 than the blood pressure measurements 602 determined for a subject 102 using the existing technique match the reference blood pressure measurements 600. Although the blood pressure measurements 606 determined for a subject 102 using the apparatus 100 and method 200 described earlier with reference to Fig. 4 still has outliers, it can be seen from Fig. 6A and 6B that the apparatus 100 and method 200 described earlier with reference to Fig. 4 provides an improved correlation than the existing technique. Thus, the apparatus 100 and method 200 described earlier with reference to Fig. 4 provides more accurate and reliable blood pressure measurements.

[0056] There is also provided a computer program

product comprising a computer readable medium. The computer readable medium has computer readable code embodied therein. The computer readable code is configured such that, on execution by a suitable computer or processor, the computer or processor is caused to perform any of the methods described herein. The computer readable medium may be, for example, any entity or device capable of carrying the computer program product. For example, the computer readable medium may include a data storage, such as a ROM (such as a CD-ROM or a semiconductor ROM) or a magnetic recording medium (such as a hard disk). Furthermore, the computer readable medium may be a transmissible carrier, such as an electric or optical signal, which may be conveyed via electric or optical cable or by radio or other means. When the computer program product is embodied in such a signal, the computer readable medium may be constituted by such a cable or other device or means. Alternatively, the computer readable medium may be an integrated circuit in which the computer program product is embedded, the integrated circuit being adapted to perform, or used in the performance of, the method described herein.

[0057] There is thus provided herein an improved apparatus and method for determining a blood pressure measurement for a subject.

[0058] Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the principles and techniques described herein, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored or distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. An apparatus (100) for determining a blood pressure measurement for a subject (102), the apparatus (100) comprising a processor (104) configured to:

   acquire, from a light sensor (106), measurements of an intensity of light (108) of a first wavelength range reflected from the skin (110) of the subject (102) and an intensity of light (112) of a second wavelength range reflected from the skin (110) of the subject (102) for a range of forces at which the light sensor (106) is applied to the skin (110) of the subject (102);
   for each of the applied forces, determine a ratio of the intensity of light (108) of the first wavelength range to the intensity of light (112) of the second wavelength range; and
   determine a blood pressure measurement for the subject (102) based on an integral of the ratios with respect to the applied forces.

2. The apparatus (100) as claimed in claim 1, wherein the second wavelength range is different to the first wavelength range.

3. The apparatus (100) as claimed in any of the preceding claims, wherein the first wavelength range is a red wavelength range or an infrared wavelength range.

4. The apparatus (100) as claimed in any of the preceding claims, wherein the second wavelength range is a green wavelength range.

5. The apparatus (100) as claimed in any of the preceding claims, wherein the processor (104) is further configured to:
   plot the determined ratio of the intensity of light (108) of the first wavelength range to the intensity of light (112) of the second wavelength range as a function of the range of forces at which the light sensor (106) is applied to the skin (110) of the subject (102).

6. The apparatus (100) as claimed in claim 5, wherein the integral of the ratios with respect to the applied forces comprises the area under the plot.

7. A system (10, 20) for determining a blood pressure measurement for a subject (102), the system (10, 20) comprising:

   the apparatus (100) as claimed in any of the preceding claims; and
   the light sensor (106), wherein the light sensor (106) is configured to:
   acquire measurements of the intensity of light (108) of the first wavelength range reflected from the skin (110) of the subject (102) and the intensity of light (112) of the second wavelength range reflected from the skin (110) of the subject (102) for the range of forces at which the light sensor (106) is applied to the skin (110) of the subject (102).

8. The system (10, 20) as claimed in claim 7, wherein the system (10, 20) further comprises:
   a force sensor (116) configured to measure the range of forces at which the light sensor (106) is ap-

plied to the skin (110) of the subject (102).

9. The system (10, 20) as claimed in any of claims 7 or 8, wherein the system (10, 20) further comprises: a light source (114) configured to emit light (108) of the first wavelength range and light (112) of the second wavelength range at the skin (110) of the subject (102).

10. The system (10, 20) as claimed in any of claims 7 to 9, wherein the system (10, 20) further comprises: an optical head (118) contactable with the skin (110) of the subject (102), wherein the optical head (118) comprises the light sensor (106).

11. The system (10, 20) as claimed in claim 10, when dependent on claim 9, wherein the optical head (118) further comprises the light source (114).

12. A method (200) for determining a blood pressure measurement for a subject (102), the method (200) comprising:

acquiring (202), from a light sensor (106), measurements of an intensity of light (108) of a first wavelength range reflected from the skin (110) of the subject (102) and an intensity of light (112) of a second wavelength range reflected from the skin (110) of the subject (102) for a range of forces at which the light sensor (106) is applied to the skin (110) of the subject (102);
for each of the applied forces, determining a ratio of the intensity of light (108) of the first wavelength range to the intensity of light (112) of the second wavelength range; and
determining a blood pressure measurement for the subject (102) based on an integral of the ratios with respect to the applied forces.

13. A computer program product comprising a computer readable medium, the computer readable medium having computer readable code embodied therein, the computer readable code being configured such that, on execution by a suitable computer or processor, the computer or processor is caused to perform the method as claimed in claim 12.

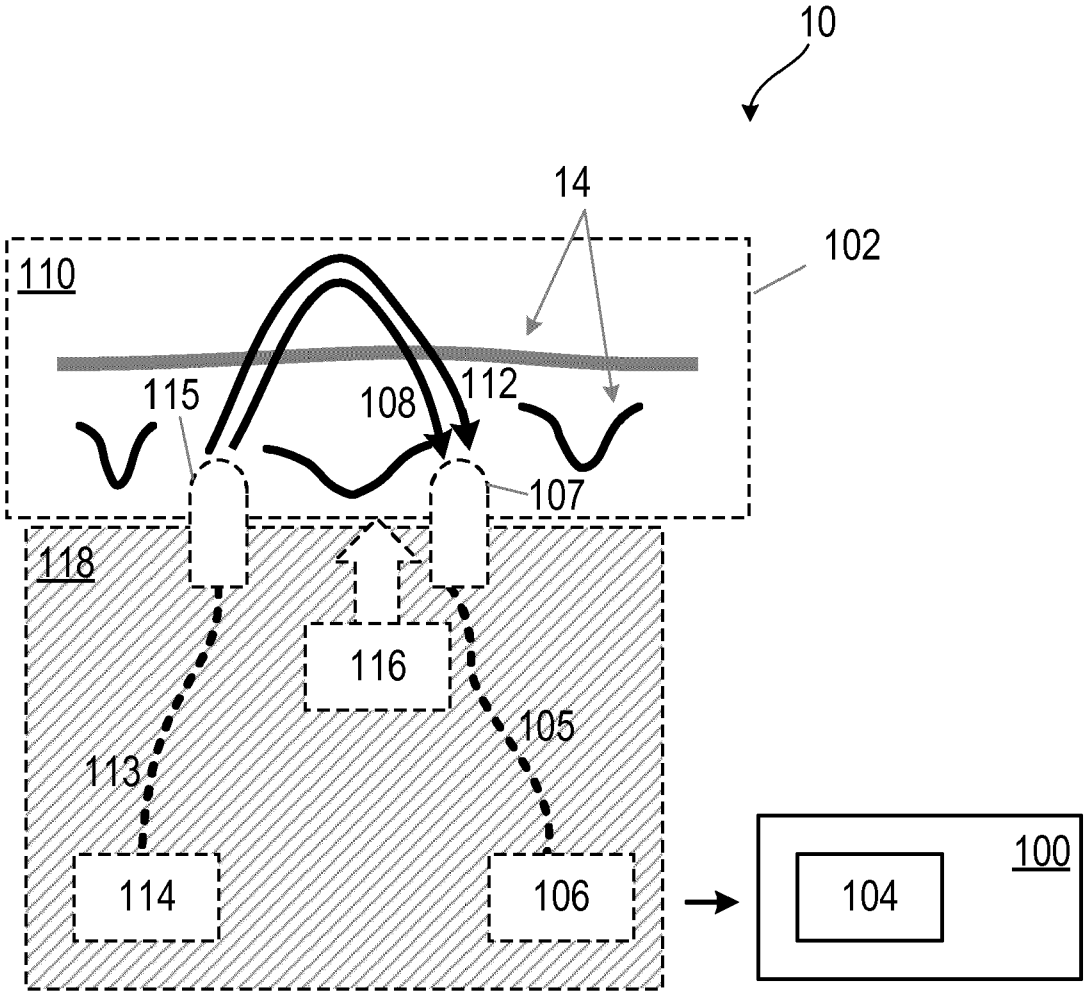

Fig. 1

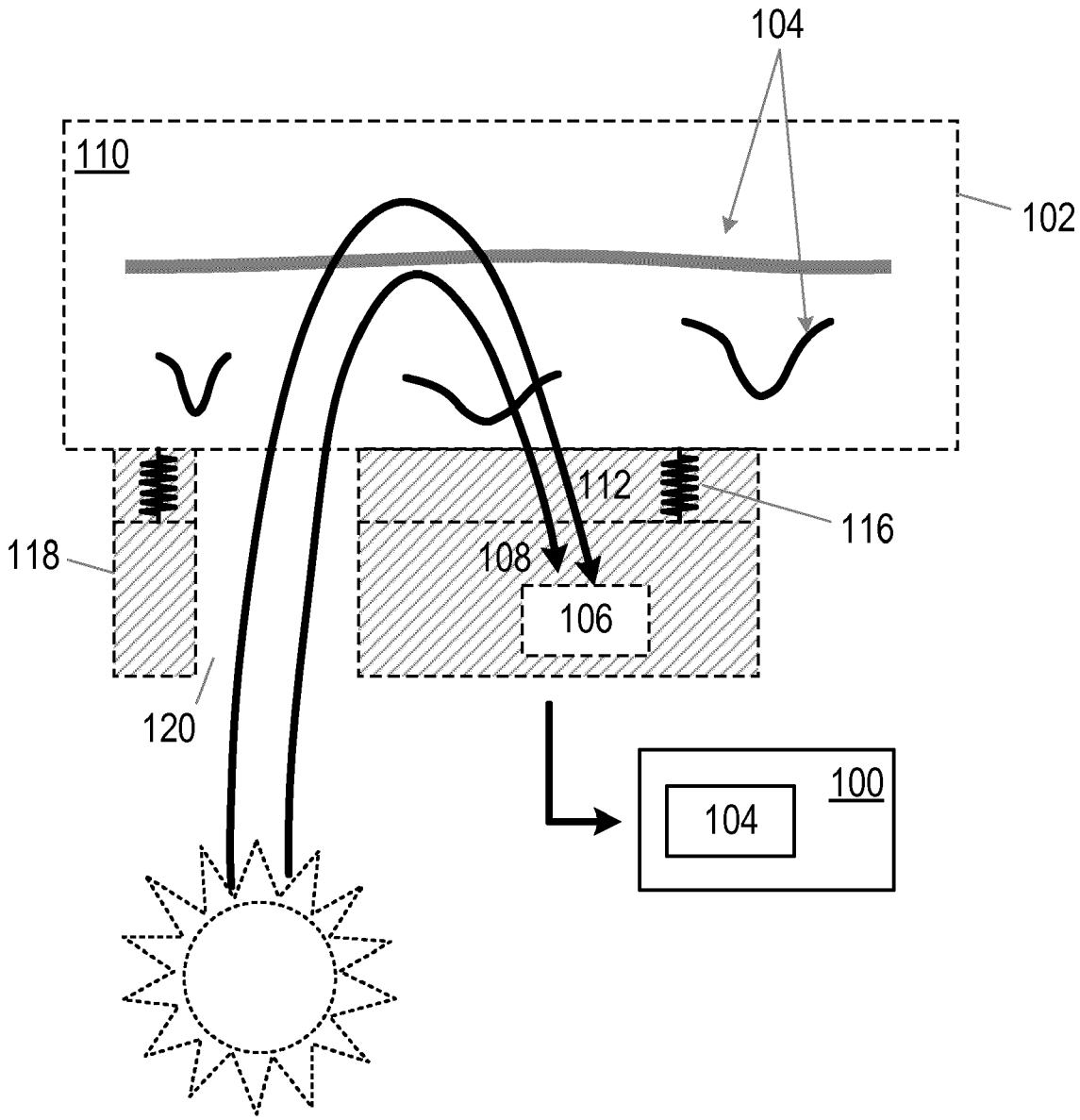

Fig. 2

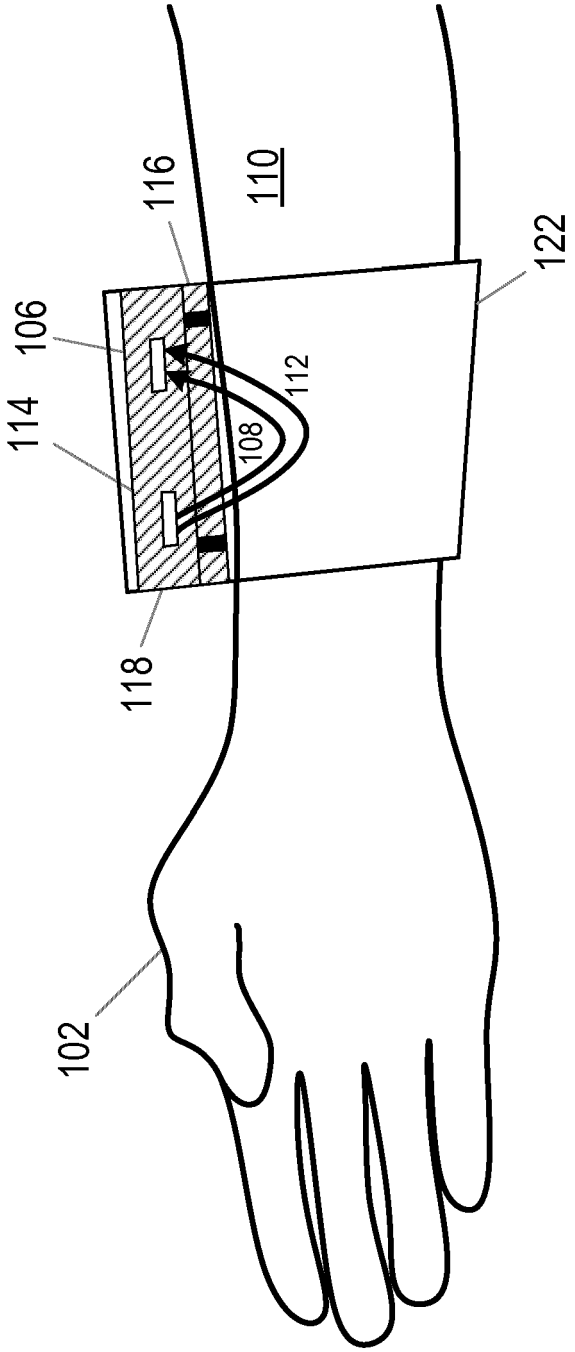

Fig. 3

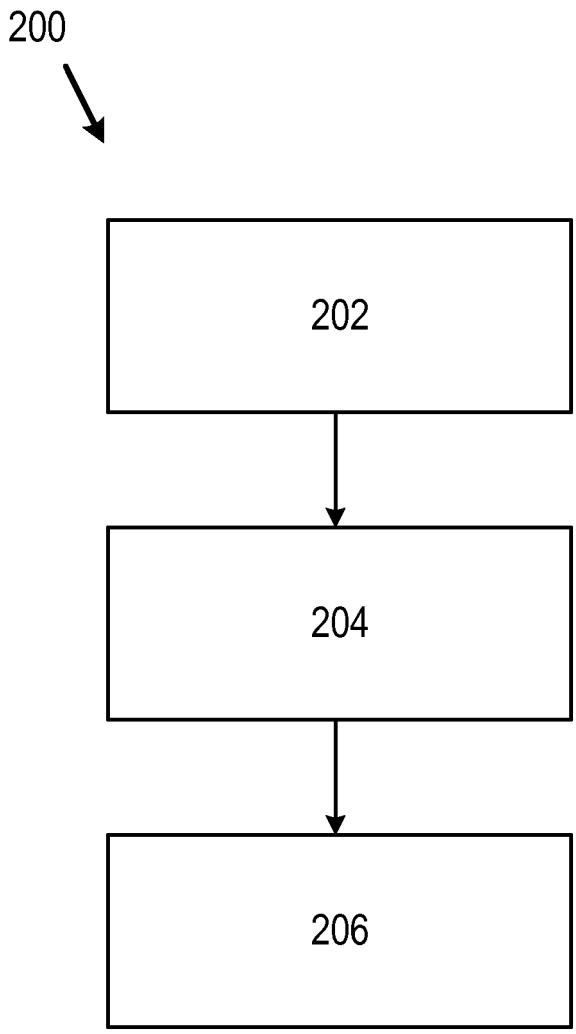

Fig. 4

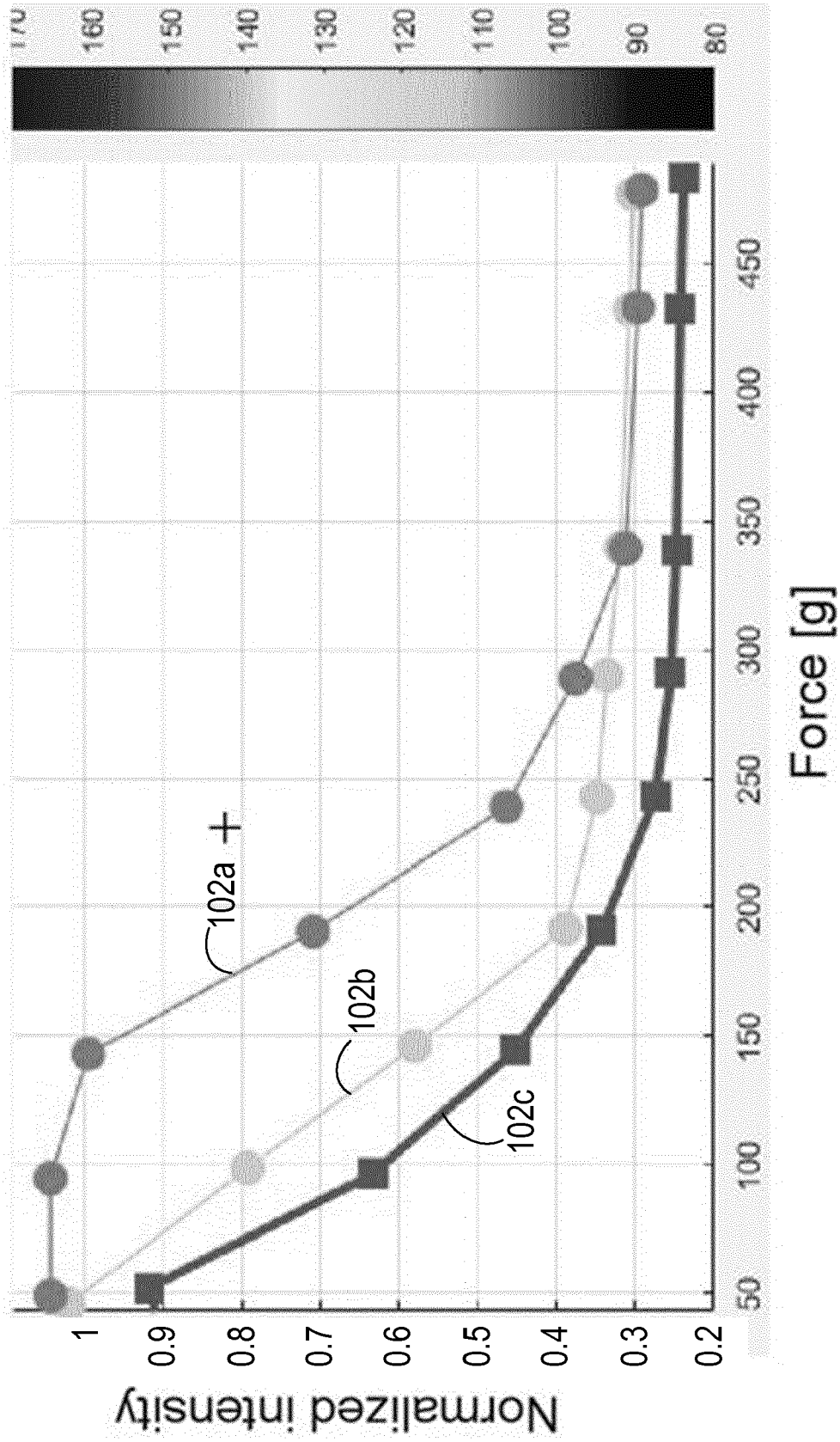
Normalized intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
50
100
150
200
250
300
350
400
450
Force [g]
102a
102b
102c
160
150
140
130
120
110
100
90
80

Fig. 5

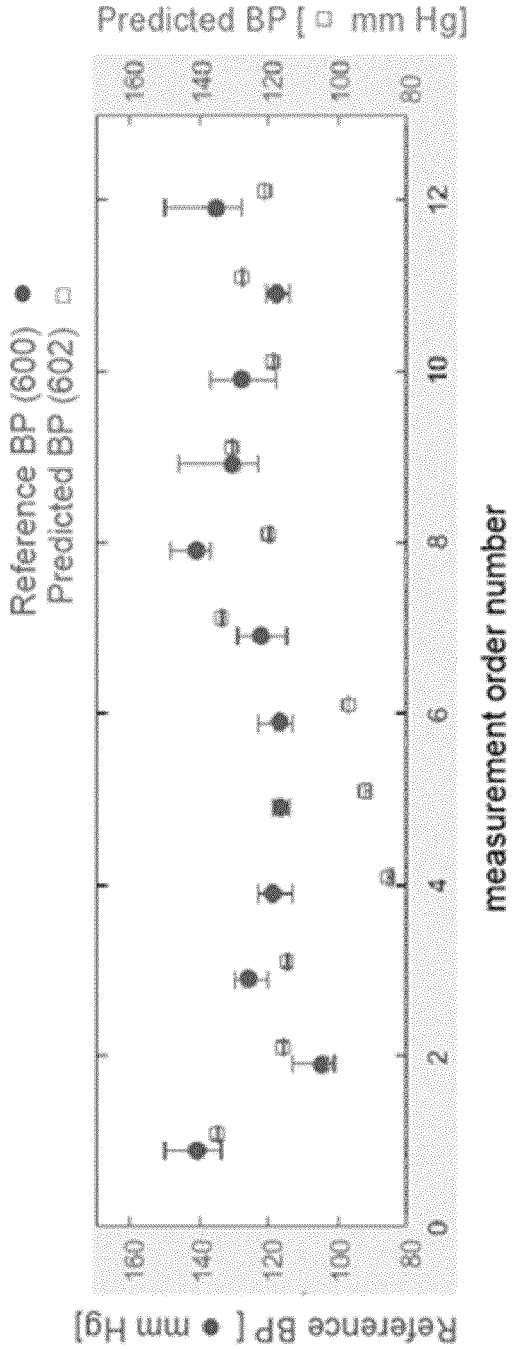

Fig. 6A (Prior Art)

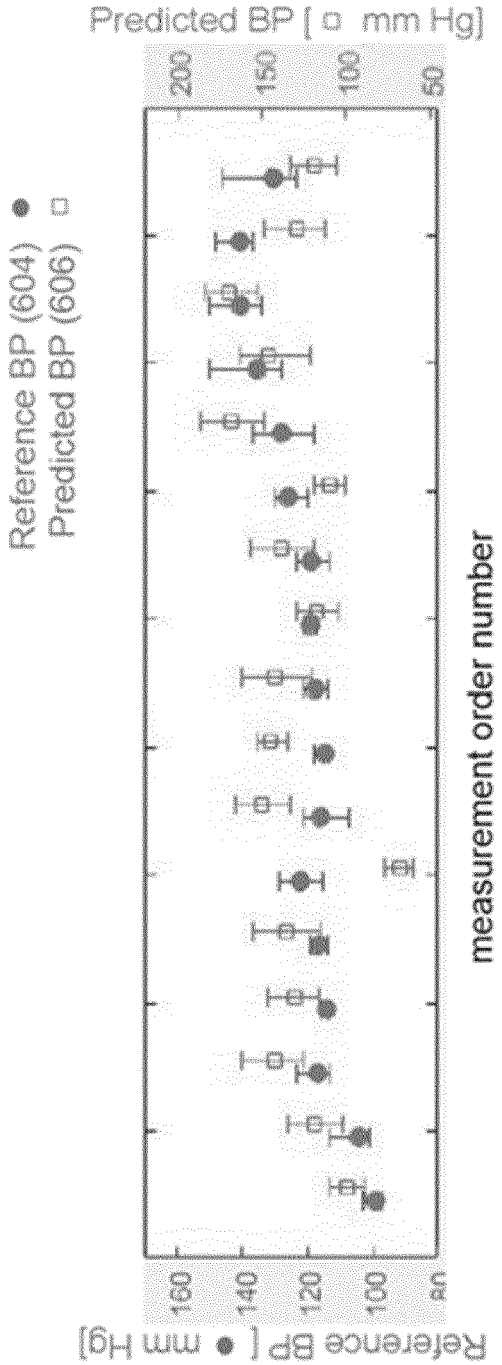

Fig. 6B

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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 1149

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	A. C. M. DASSEL ET AL: "Reflectance pulse oximetry at the forehead improves by pressure on the probe", JOURNAL OF CLINICAL MONITORING, vol. 11, no. 4, 1 July 1995 (1995-07-01), pages 237-244, XP055514417, Dordrecht ISSN: 0748-1977, DOI: 10.1007/BF01617518 * page 238, right-hand column, line 25 - page 240, right-hand column, line 5; figures 1, 3-4 * * the whole document * -----	1-13	INV. A61B5/00 A61B5/022 A61B5/024
A	TENG X F ET AL: "The effect of contacting force on photoplethysmographic signals; The effect of contacting force on photoplethysmographic signals", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 25, no. 5, 1 October 2004 (2004-10-01), pages 1323-1335, XP020074200, ISSN: 0967-3334, DOI: 10.1088/0967-3334/25/5/020 * section 2.1; figure 1 * * sections 3.1 to 3.5; figures 6-8 * * section 4.1 * * section 4.3 * -----	1-13	TECHNICAL FIELDS SEARCHED (IPC) A61B

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	12 October 2018	Sarcia, Regis

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons

& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 1149

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	BLAXTER L L ET AL: "An automated quasi-continuous capillary refill timing device", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 37, no. 1, 7 December 2015 (2015-12-07), pages 83-99, XP020292164, ISSN: 0967-3334, DOI: 10.1088/0967-3334/37/1/83 [retrieved on 2015-12-07] * abstract * * section 3.1; figure 1 * * page 83, lines 18-19 * * the whole document * -----	4	
A	PEDRO SANTOS ET AL: "Photoplethysmographic logger with contact force and hydrostatic pressure monitoring", BIOENGINEERING (ENBENG), 2013 IEEE 3RD PORTUGUESE MEETING IN, IEEE, 20 February 2013 (2013-02-20), pages 1-6, XP032410163, DOI: 10.1109/ENBENG.2013.6518437 ISBN: 978-1-4673-4859-1 * the whole document * -----	1	TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

4

Place of search	Date of completion of the search	Examiner
The Hague	12 October 2018	Sarcia, Regis

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2005131356 A **[0004]**

专利名称(译)	用于确定血压测量值的装置		
公开(公告)号	EP3566641A1	公开(公告)日	2019-11-13
申请号	EP2018171149	申请日	2018-05-08
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	ASVADI SIMA PRESURA CRISTIAN NICOLAE		
发明人	ASVADI, SIMA PRESURA, CRISTIAN NICOLAE MILICI, ALINA		
IPC分类号	A61B5/00 A61B5/022 A61B5/024		
CPC分类号	A61B5/0053 A61B5/0075 A61B5/022 A61B5/02416 A61B5/14551 A61B5/681 A61B5/6814 A61B5/6823 A61B5/6824 A61B5/6831 A61B5/6832 A61B5/6843 A61B2560/0209		
代理机构(译)	德哈恩波尔ERIK		
审查员(译)	SARCIA，吉斯		
外部链接	Espacenet		

摘要(译)

提供了一种用于确定对象（102）的血压测量值的设备（100）。装置（100）包括处理器（104），其被配置为从光传感器（106）获取从受检者（102）的皮肤（110）反射的第一波长范围的光（108）的强度的测量值。从受检者（102）的皮肤（110）反射的第二波长范围的光（112）的强度为光传感器（106）施加到皮肤（110）的力的范围。处理器（104）还被配置为针对每个施加的力确定第一波长范围的光（108）的强度与第二波长范围的光（112）的强度的比率，并确定血压测量值根据相对于所施加力的比率的积分来确定受检者（102）的压力。

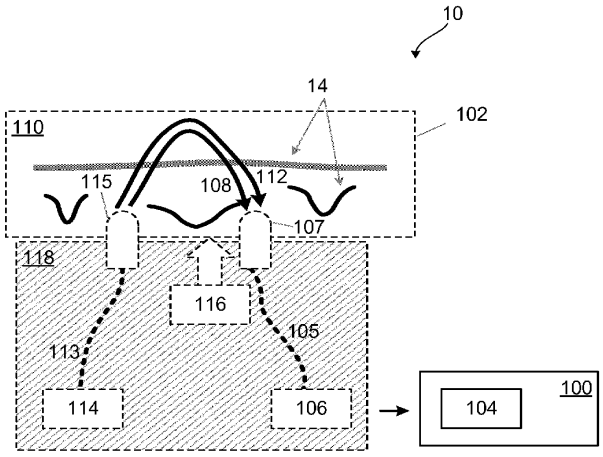

Fig. 1