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(54) SYSTEMS AND METHODS OF SWIMMING CALORIMETRY

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(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

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A61B 5/0205	(2006.01)

(52) **U.S. Cl.**

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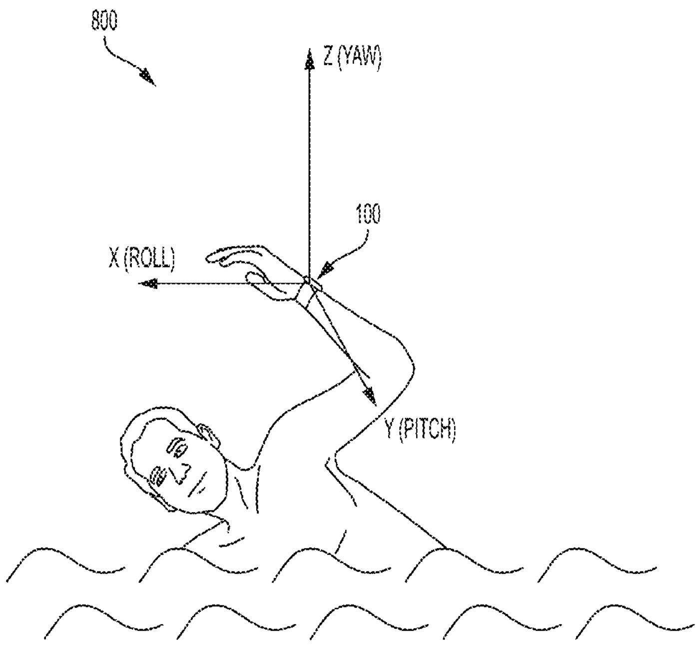
(57) **ABSTRACT**

The present disclosure relates to systems and methods of estimating energy expenditure of a user while swimming. A processor circuit of a user device can estimate a speed of the user based on a stroke rate and a stroke length. The processor circuit can estimate an efficiency of the user. The processor circuit can classify a swimming style of the user. The processor circuit can determine energy expenditure of the user based on the speed, the efficiency, and the style. The processor circuit can also detect glides of the user and adjust the energy expenditure.



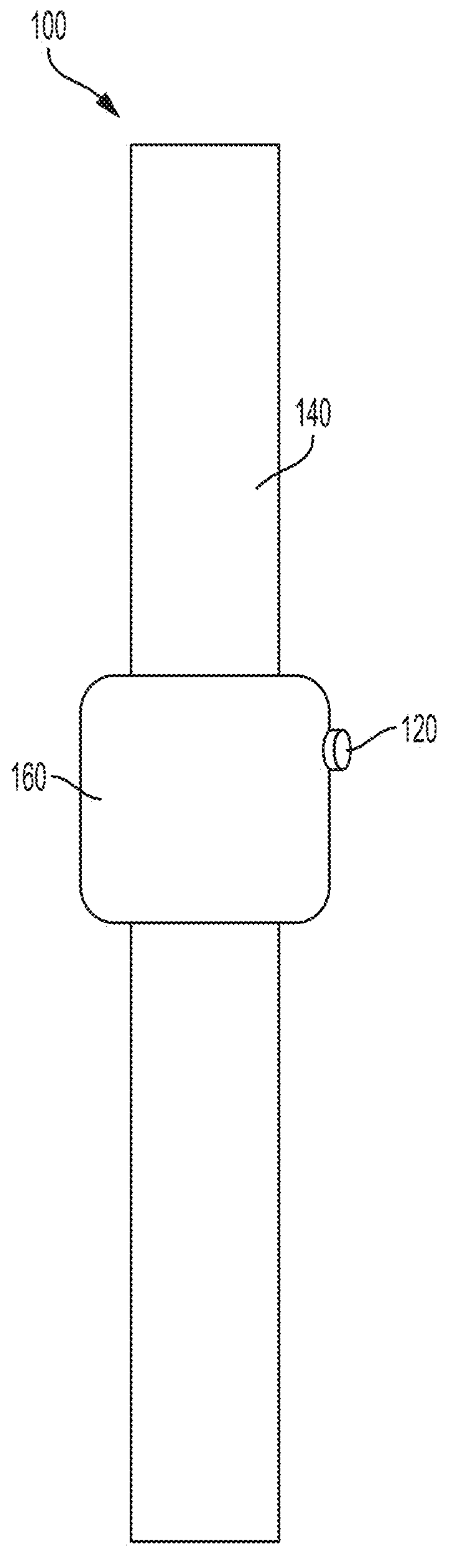


FIG. 1

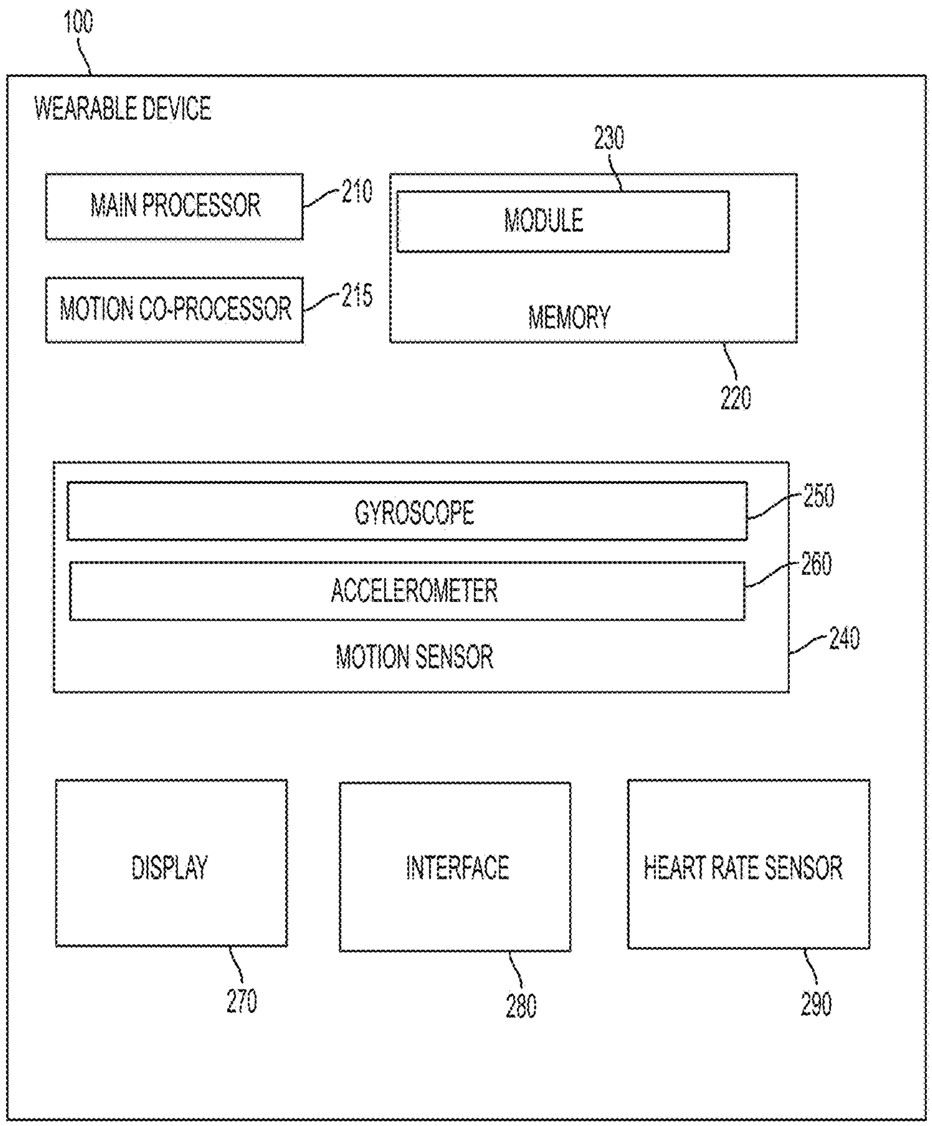

100
WEARABLE DEVICE
MAIN PROCESSOR
210
MOTION CO-PROCESSOR
215
230
MODULE
MEMORY
220
GYROSCOPE
250
ACCELEROMETER
260
MOTION SENSOR
240
DISPLAY
270
INTERFACE
280
HEART RATE SENSOR
290

FIG. 2

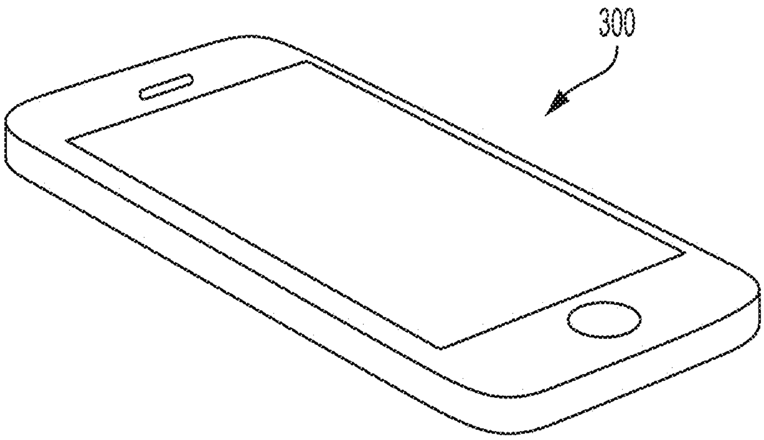


FIG. 3

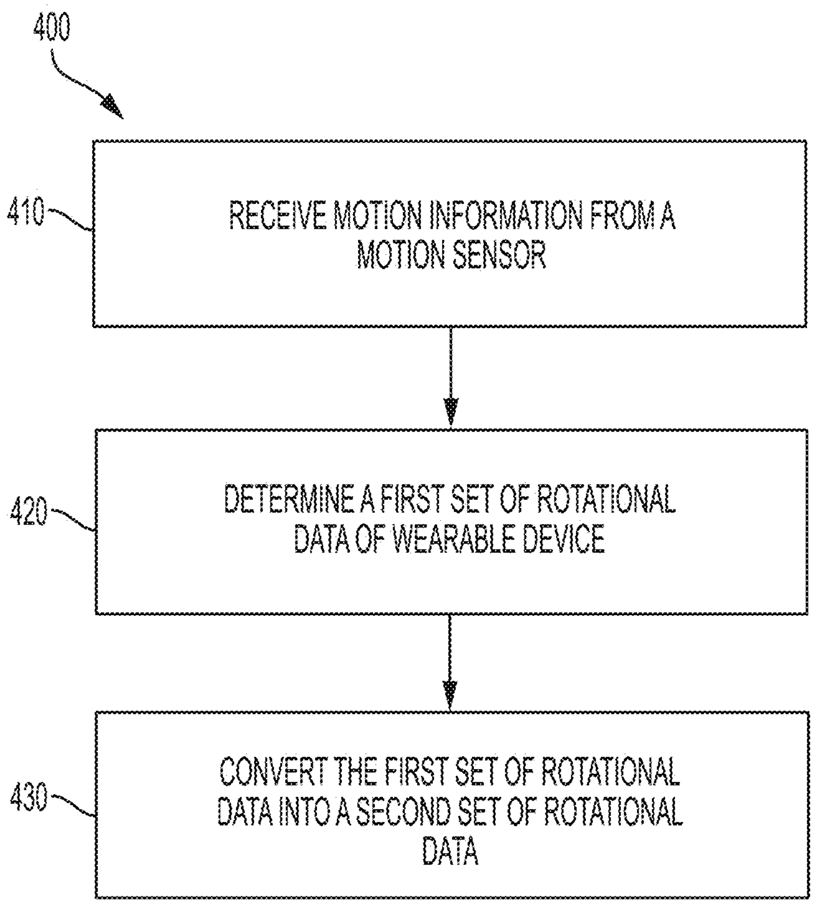

400
410
RECEIVE MOTION INFORMATION FROM A MOTION SENSOR
420
DETERMINE A FIRST SET OF ROTATIONAL DATA OF WEARABLE DEVICE
430
CONVERT THE FIRST SET OF ROTATIONAL DATA INTO A SECOND SET OF ROTATIONAL DATA

FIG. 4

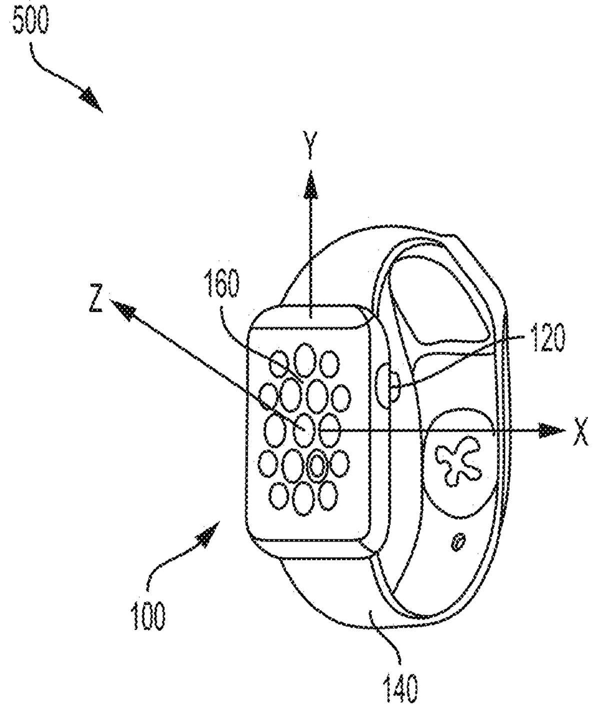


FIG. 5A

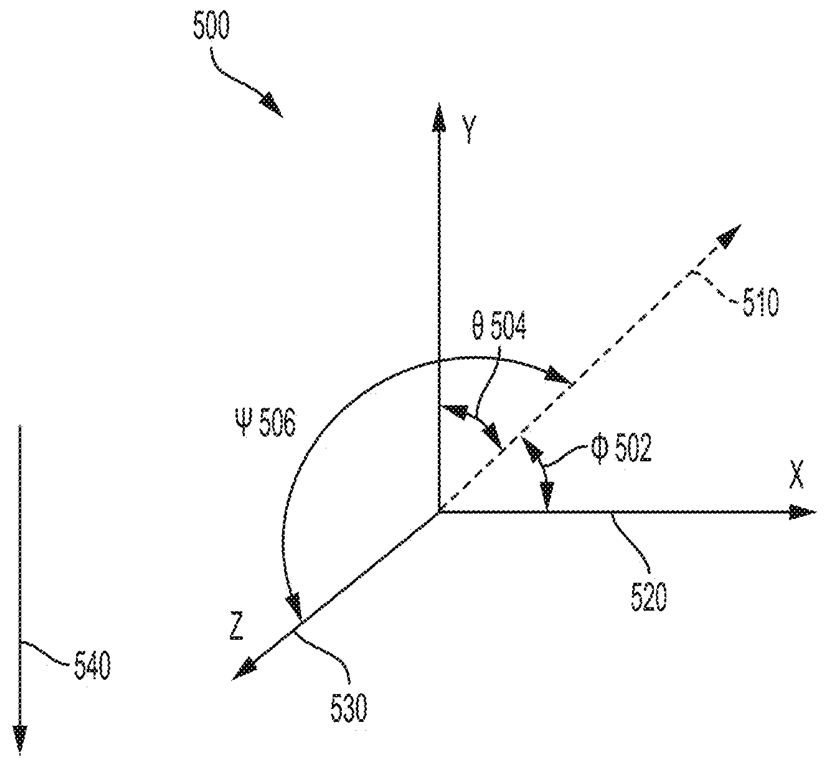


FIG. 5B

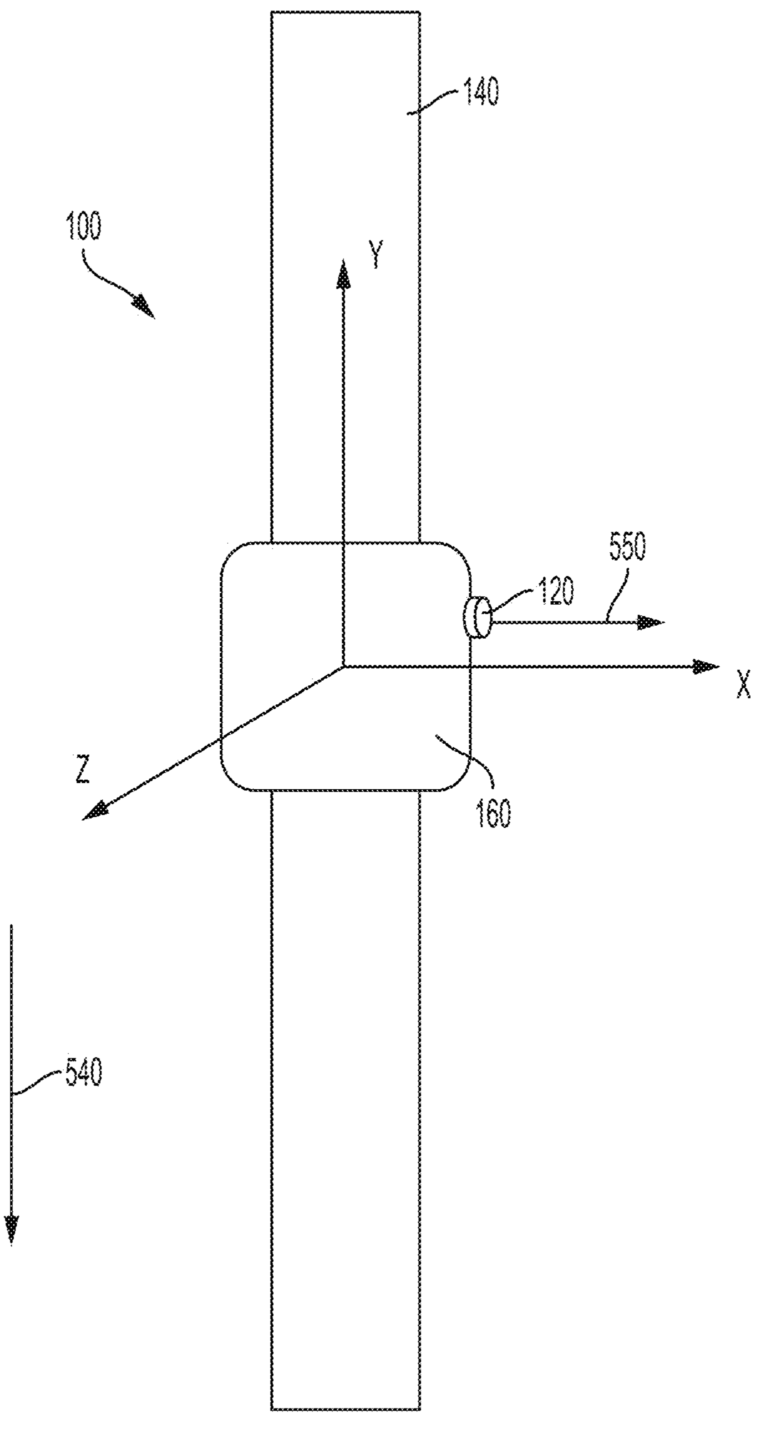


FIG. 5C

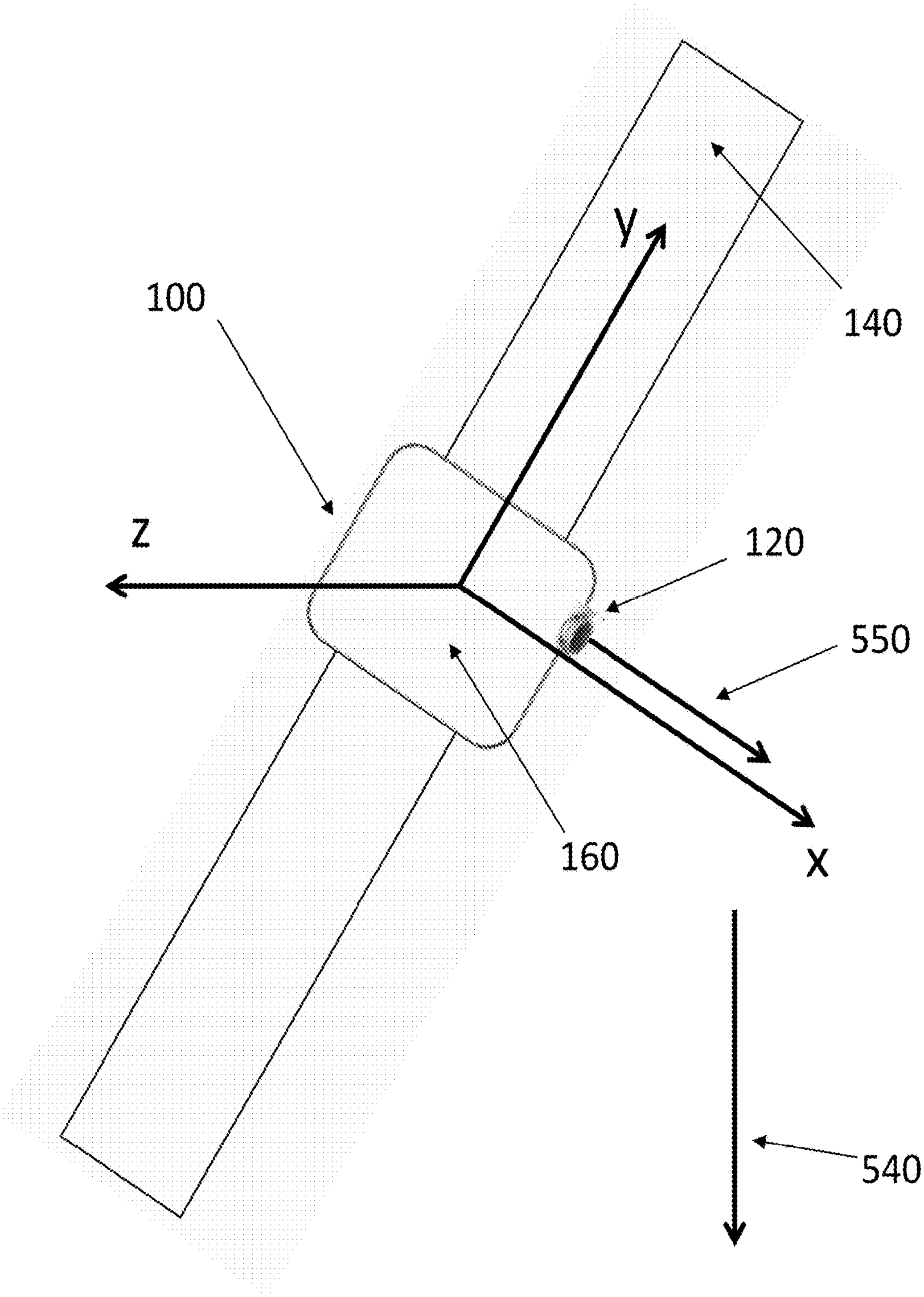


FIG. 5D

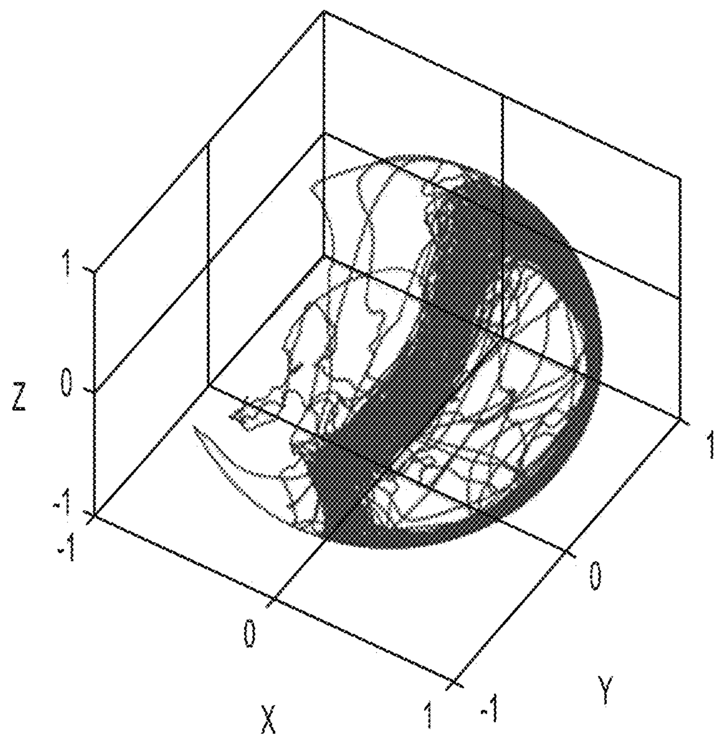


FIG. 6

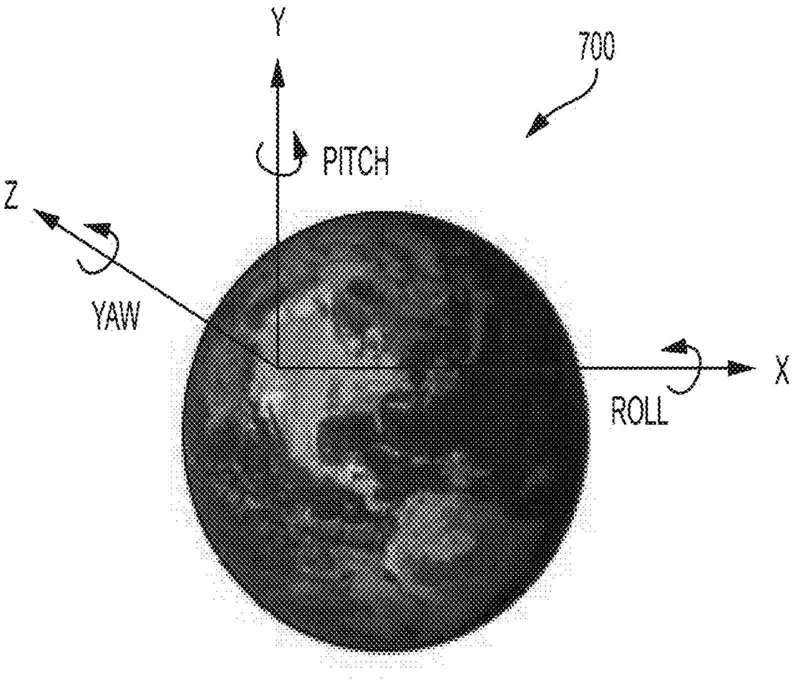


FIG. 7

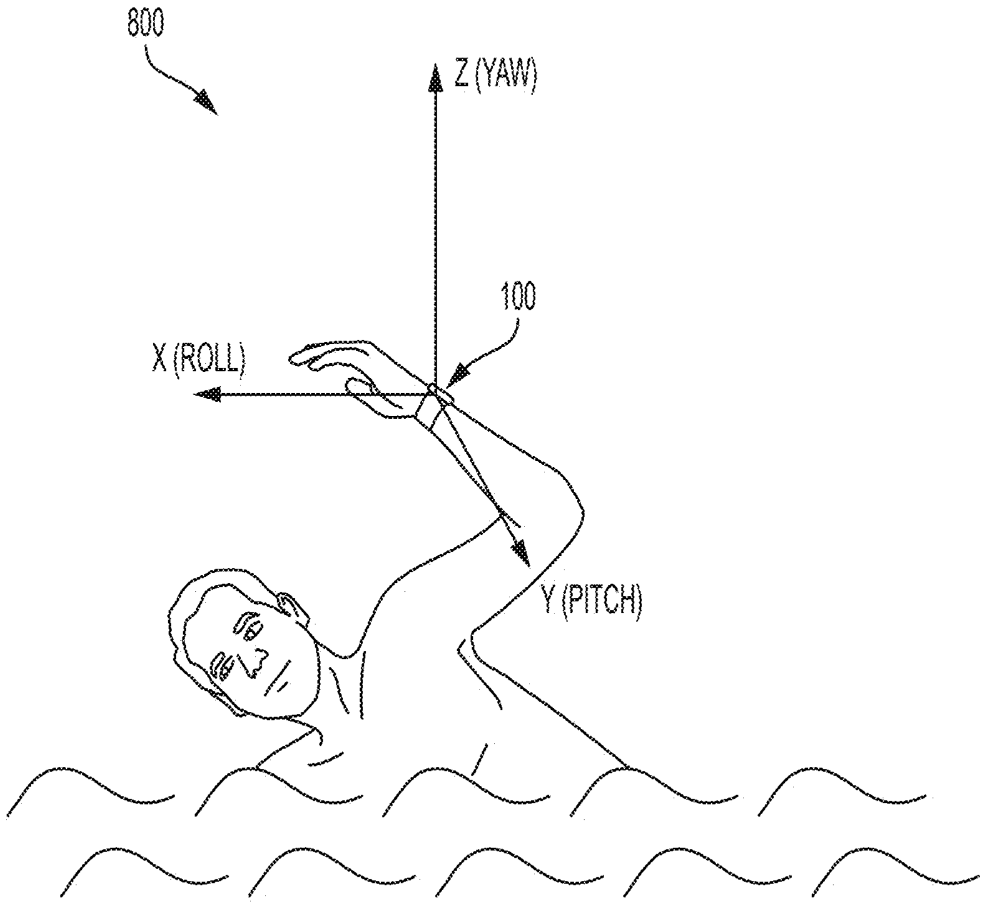


FIG. 8A

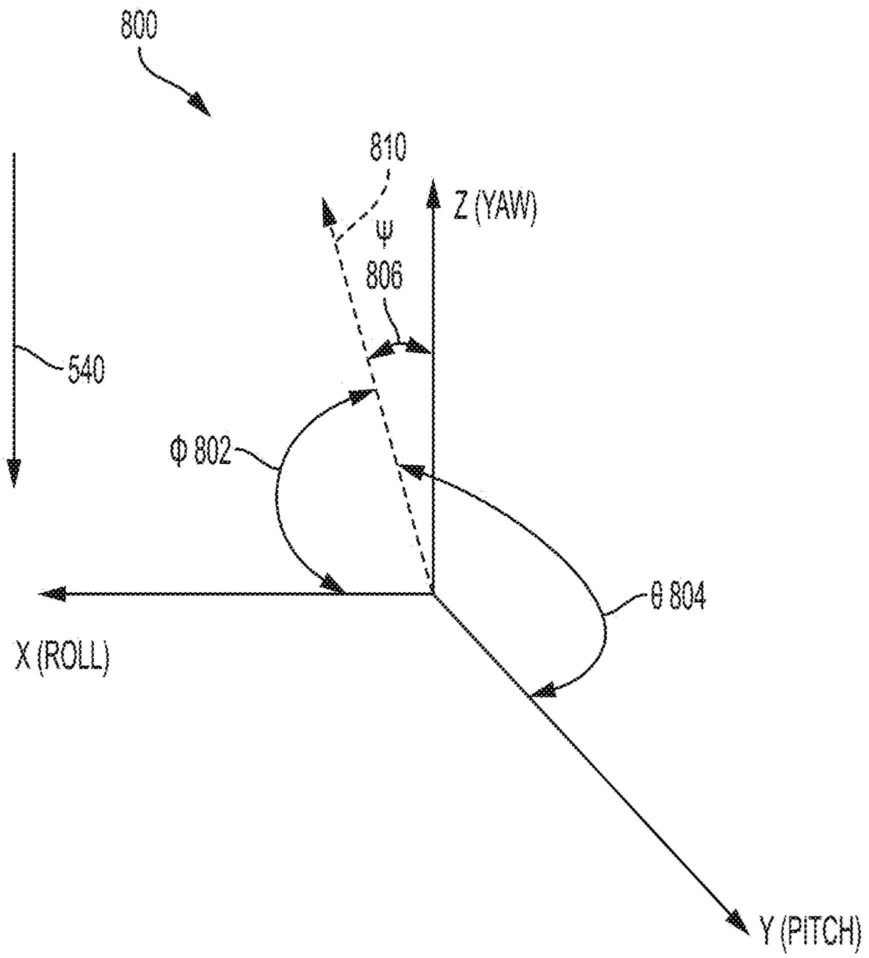


FIG. 8B

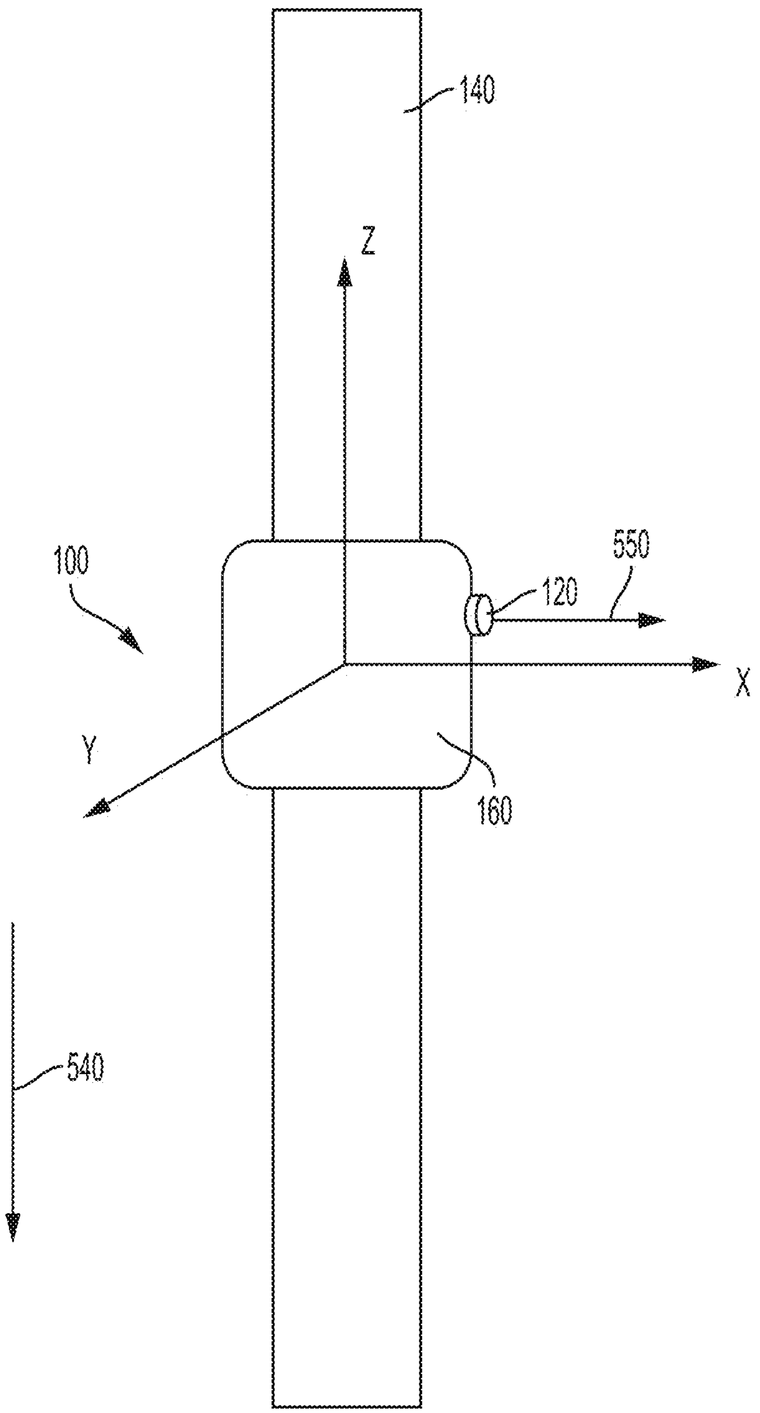


FIG. 8C

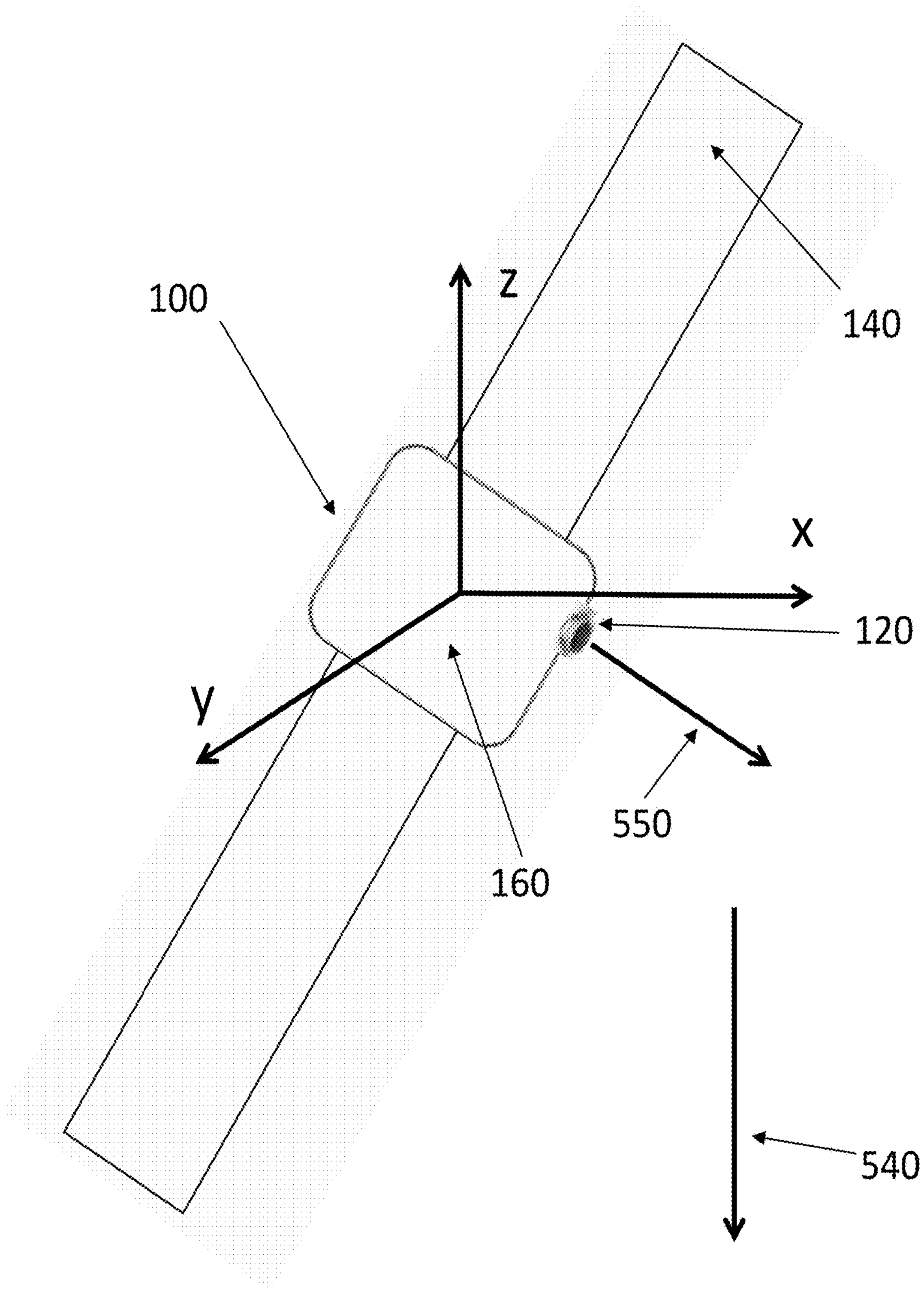


FIG. 8D

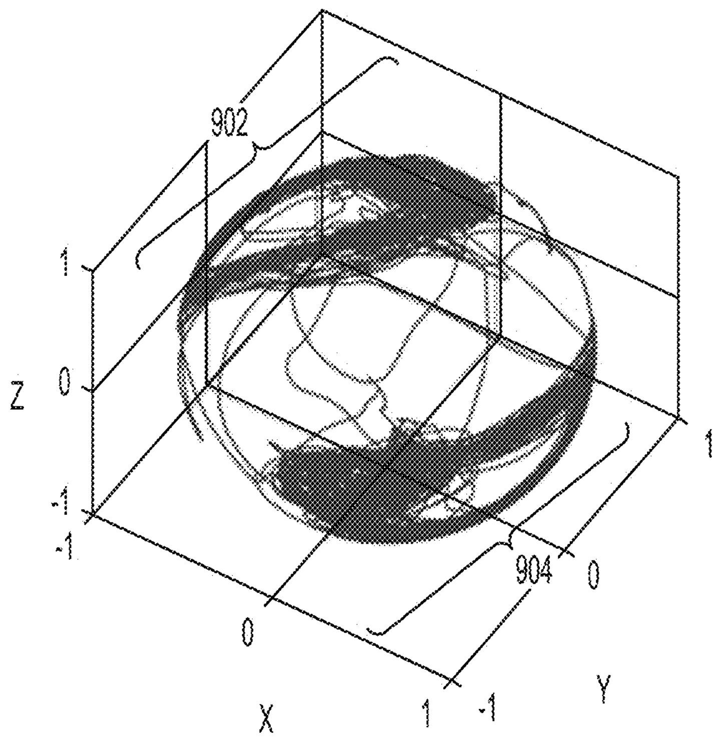


FIG. 9

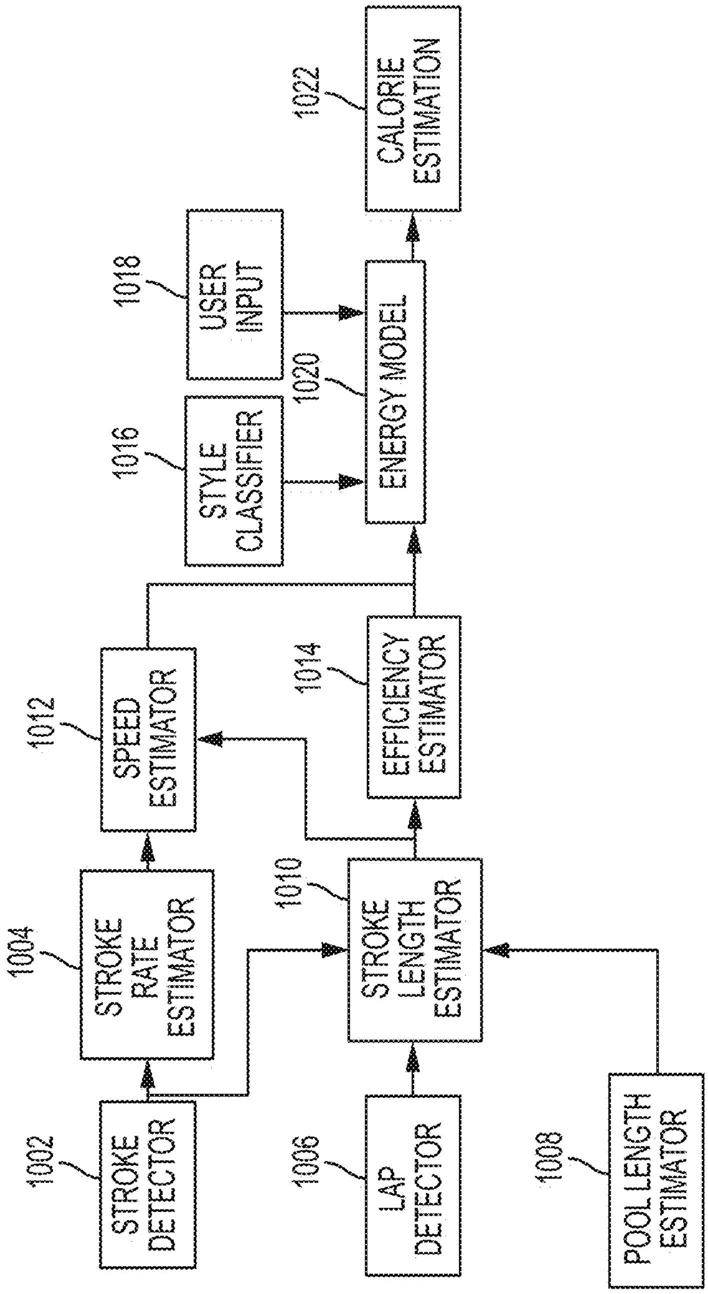

1002
STROKE DETECTOR
1004
STROKE RATE ESTIMATOR
1006
LAP DETECTOR
1008
POOL LENGTH ESTIMATOR
1010
STROKE LENGTH ESTIMATOR
1012
SPEED ESTIMATOR
1014
EFFICIENCY ESTIMATOR
1016
STYLE CLASSIFIER
1018
USER INPUT
1020
ENERGY MODEL
1022
CALORIE ESTIMATION

FIG. 10

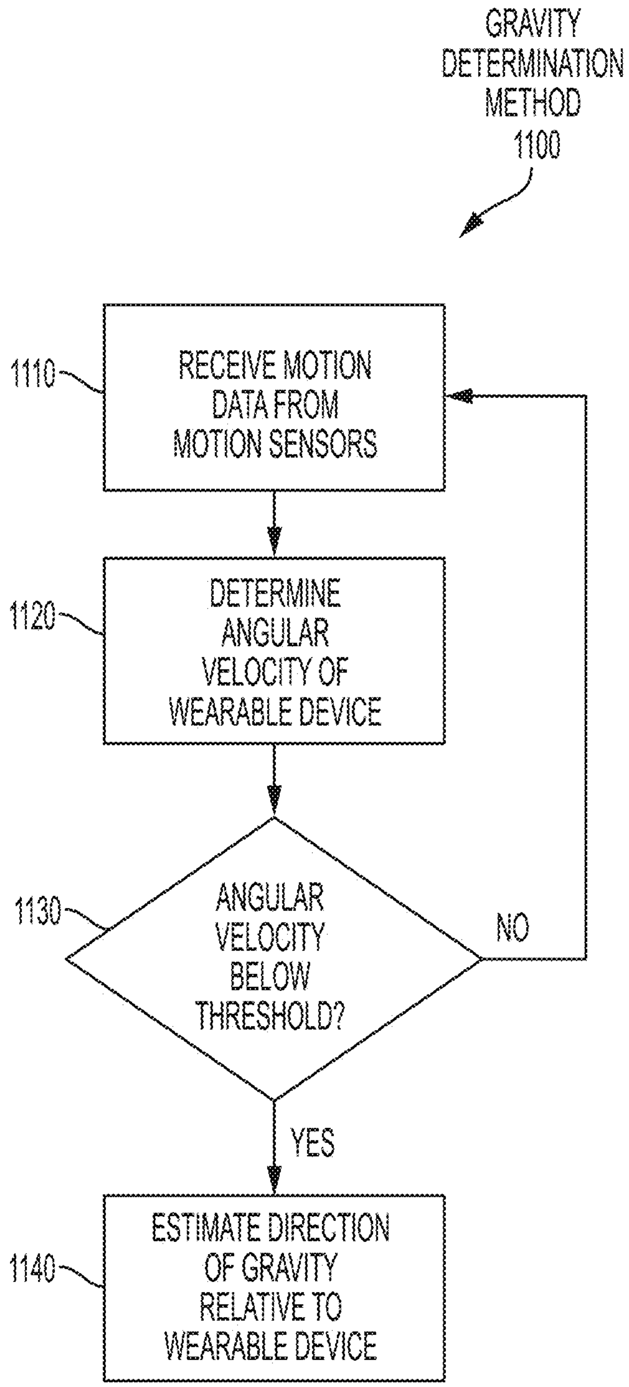

GRAVITY DETERMINATION METHOD 1100
1110
RECEIVE MOTION DATA FROM MOTION SENSORS
1120
DETERMINE ANGULAR VELOCITY OF WEARABLE DEVICE
1130
ANGULAR VELOCITY BELOW THRESHOLD?
NO
YES
1140
ESTIMATE DIRECTION OF GRAVITY RELATIVE TO WEARABLE DEVICE

FIG. 11

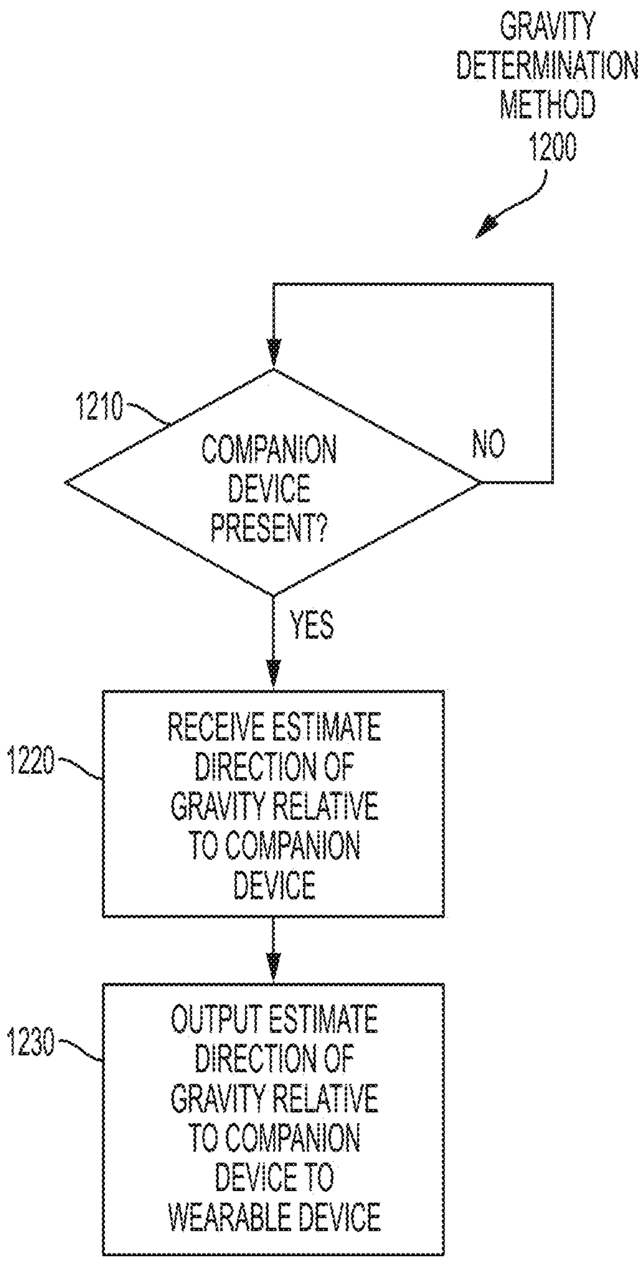

GRAVITY
DETERMINATION
METHOD
1200
1210
COMPANION
DEVICE
PRESENT?
NO
YES
1220
RECEIVE ESTIMATE
DIRECTION OF
GRAVITY RELATIVE
TO COMPANION
DEVICE
1230
OUTPUT ESTIMATE
DIRECTION OF
GRAVITY RELATIVE
TO COMPANION
DEVICE TO
WEARABLE DEVICE

FIG. 12

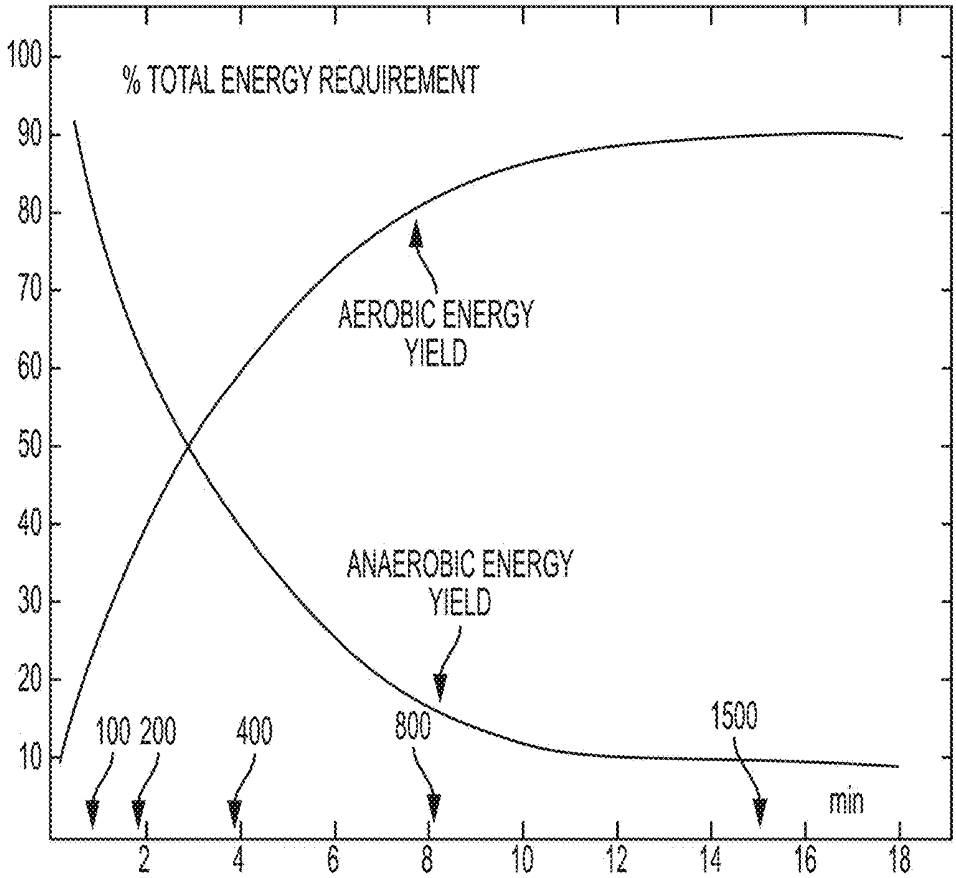

% TOTAL ENERGY REQUIREMENT
AEROBIC ENERGY YIELD
ANAEROBIC ENERGY YIELD
100
90
80
70
60
50
40
30
20
10
100 200
400
800
1500
min
2
4
6
8
10
12
14
16
18

FIG. 13

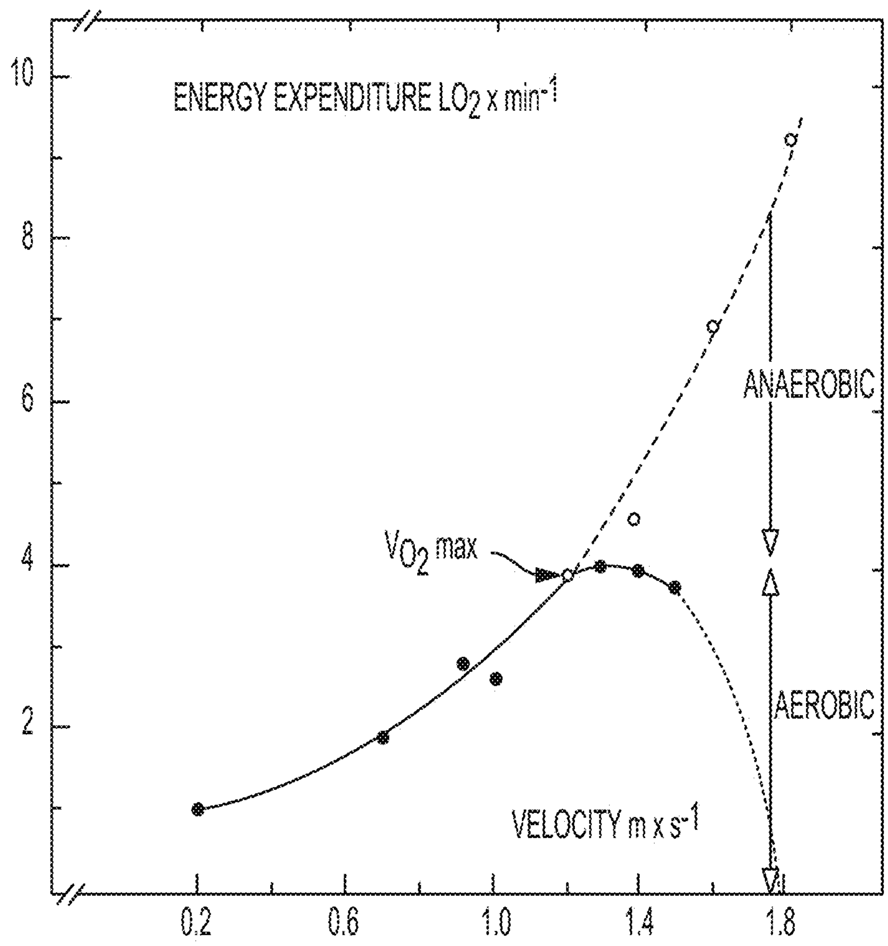

10
8
6
4
2
ENERGY EXPENDITURE LO_2 x min^{-1}
ANAEROBIC
V_{O_2} max
AEROBIC
VELOCITY m x s^{-1}
0.2
0.6
1.0
1.4
1.8

FIG. 14

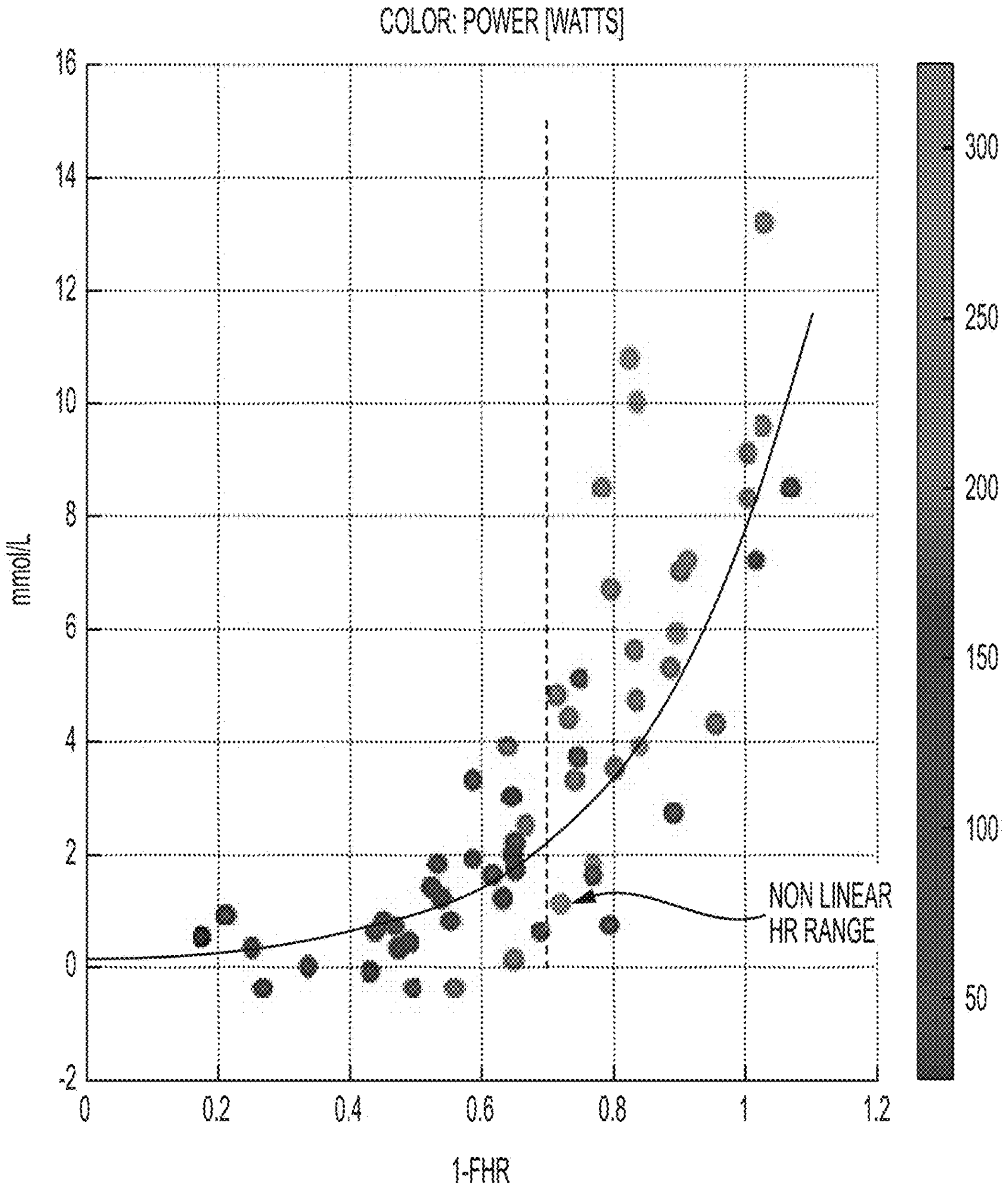

COLOR: POWER [WATTS]
mmol/L
1-FHR
16
14
12
10
8
6
4
2
0
-2
0
0.2
0.4
0.6
0.8
1
1.2
300
250
200
150
100
50
NON LINEAR
HR RANGE

FIG. 15

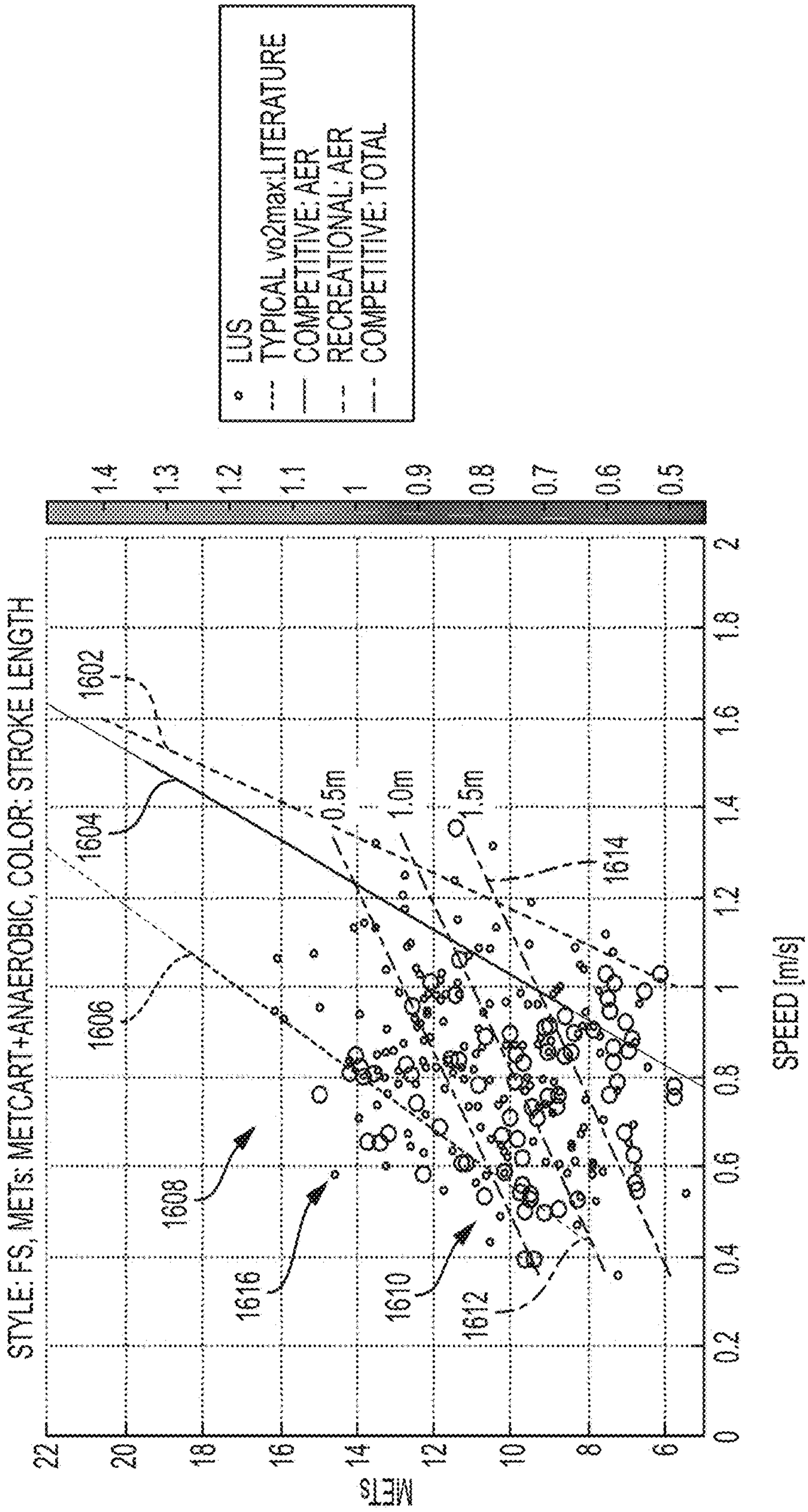

STYLE: FS, METs: METCART+ANAEROBIC, COLOR: STROKE LENGTH
LUS
TYPICAL vo2max:LITERATURE
COMPETITIVE: AER
RECREATIONAL: AER
COMPETITIVE: TOTAL
1602
1604
1606
1608
1610
1612
1614
1616
0.5m
1.0m
1.5m
METs
SPEED [m/s]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
6
8
10
12
14
16
18
20
22
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4

FIG. 16

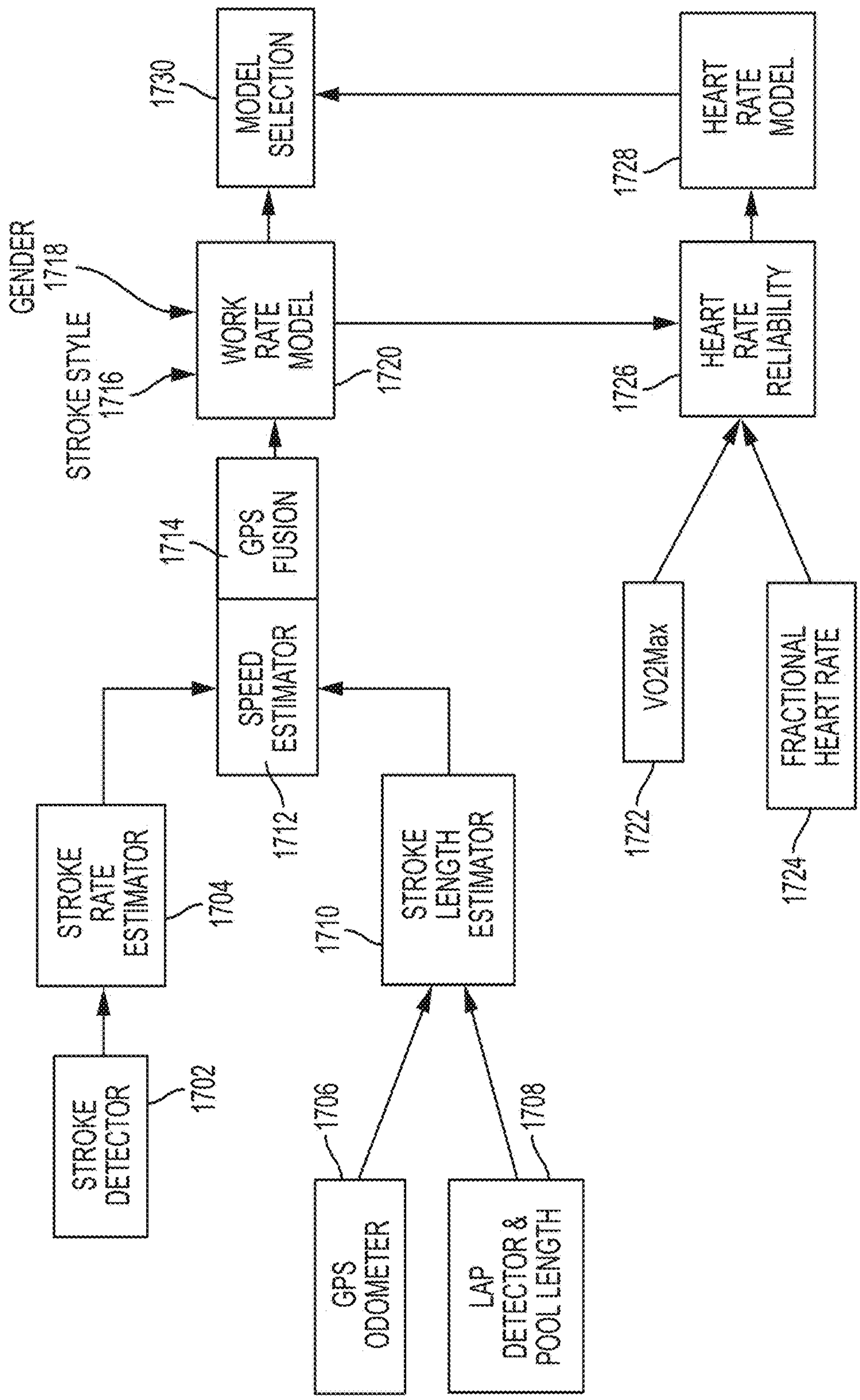

STROKE DETECTOR
1702
STROKE RATE ESTIMATOR
1704
GPS ODOMETER
1706
LAP DETECTOR & POOL LENGTH
1708
STROKE LENGTH ESTIMATOR
1710
SPEED ESTIMATOR
1712
GPS FUSION
1714
STROKE STYLE 1716
GENDER 1718
WORK RATE MODEL
1720
VO2Max
1722
FRACTIONAL HEART RATE
1724
HEART RATE RELIABILITY
1726
HEART RATE MODEL
1728
MODEL SELECTION
1730

FIG. 17

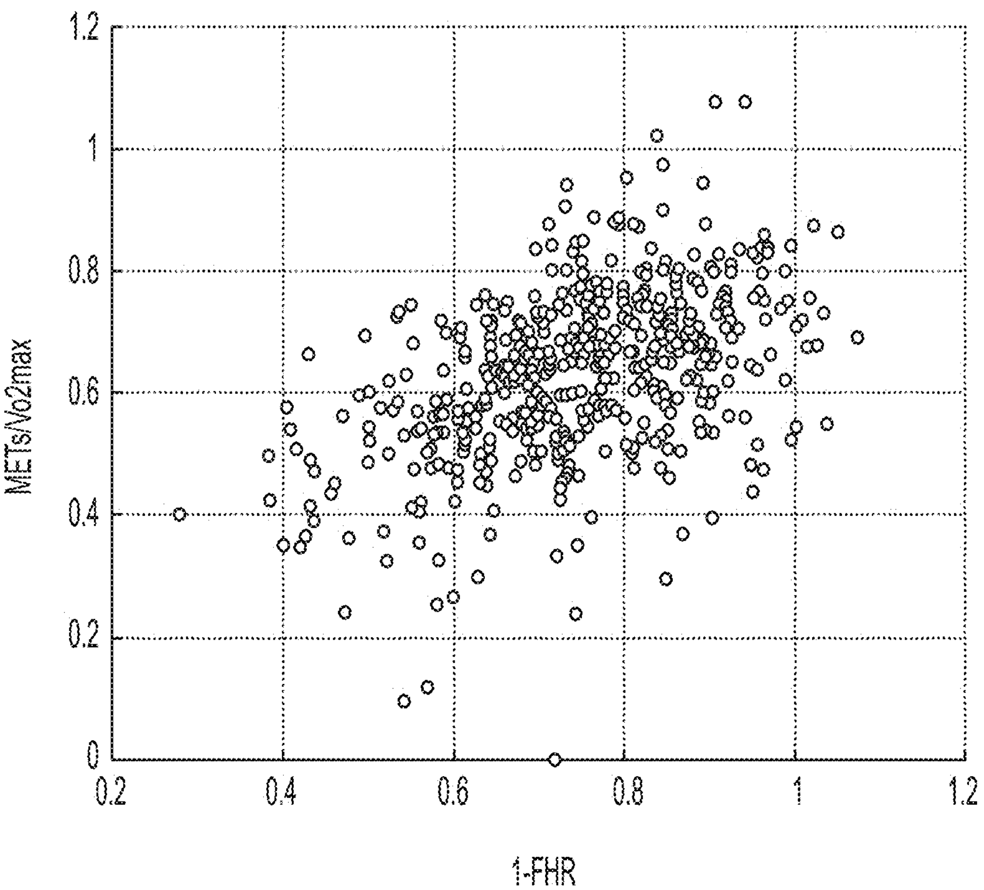


FIG. 18

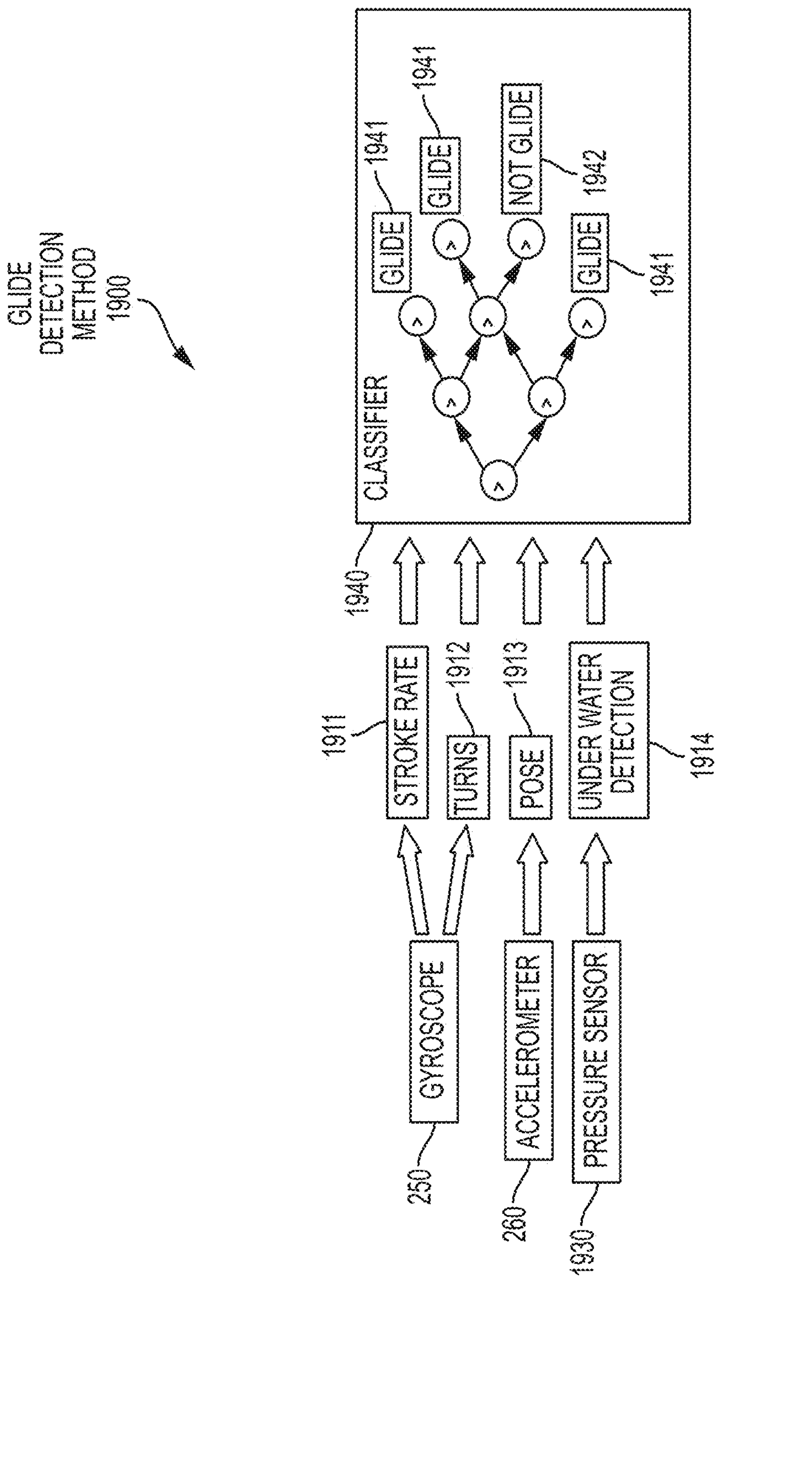

GLIDE DETECTION METHOD 1900
GYROSCOPE
250
ACCELEROMETER
260
PRESSURE SENSOR
1930
STROKE RATE
1911
TURNS
1912
POSE
1913
UNDER WATER DETECTION
1914
1940
CLASSIFIER
GLIDE
1941
GLIDE
1941
NOT GLIDE
1942
GLIDE
1941

FIG. 19

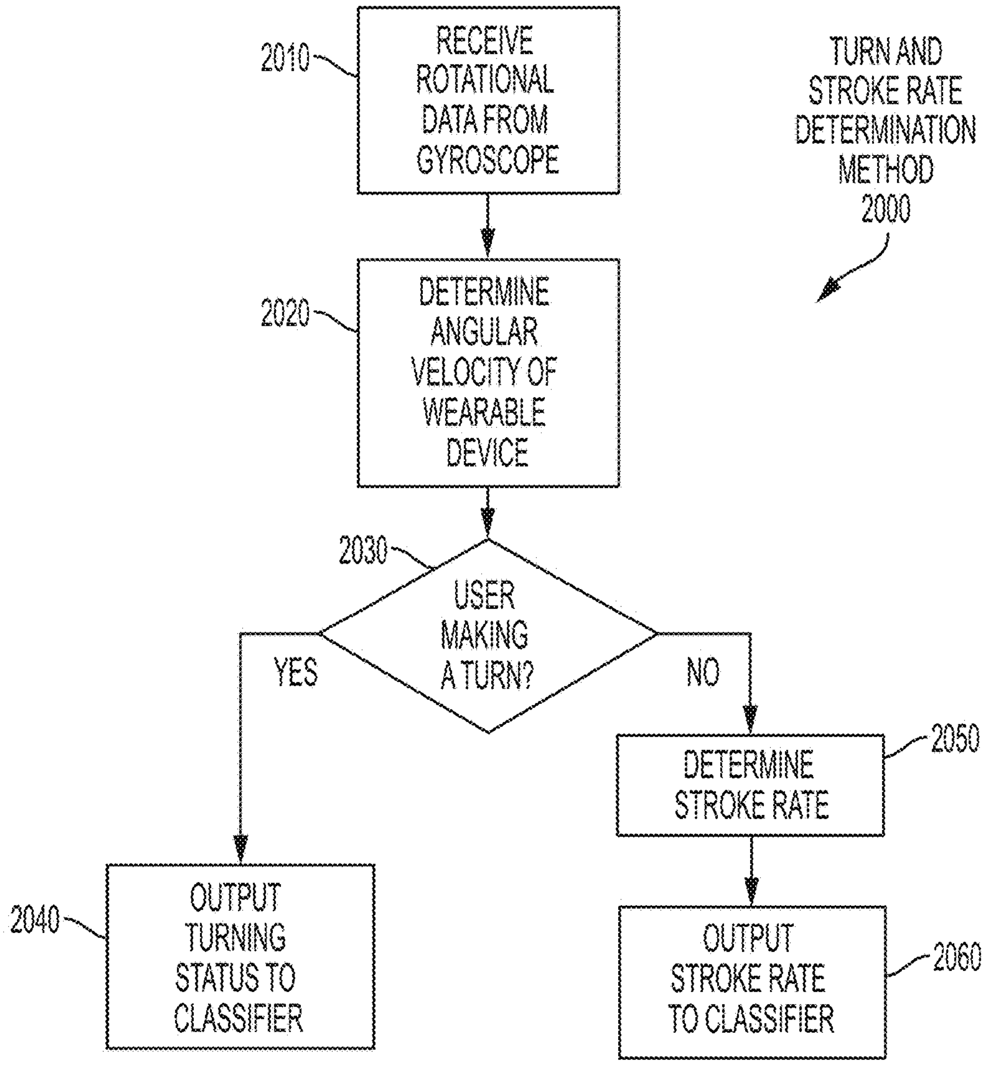

TURN AND
STROKE RATE
DETERMINATION
METHOD
2000
2010
RECEIVE
ROTATIONAL
DATA FROM
GYROSCOPE
2020
DETERMINE
ANGULAR
VELOCITY OF
WEARABLE
DEVICE
2030
USER
MAKING
A TURN?
YES
NO
2040
OUTPUT
TURNING
STATUS TO
CLASSIFIER
2050
DETERMINE
STROKE RATE
2060
OUTPUT
STROKE RATE
TO CLASSIFIER

FIG. 20

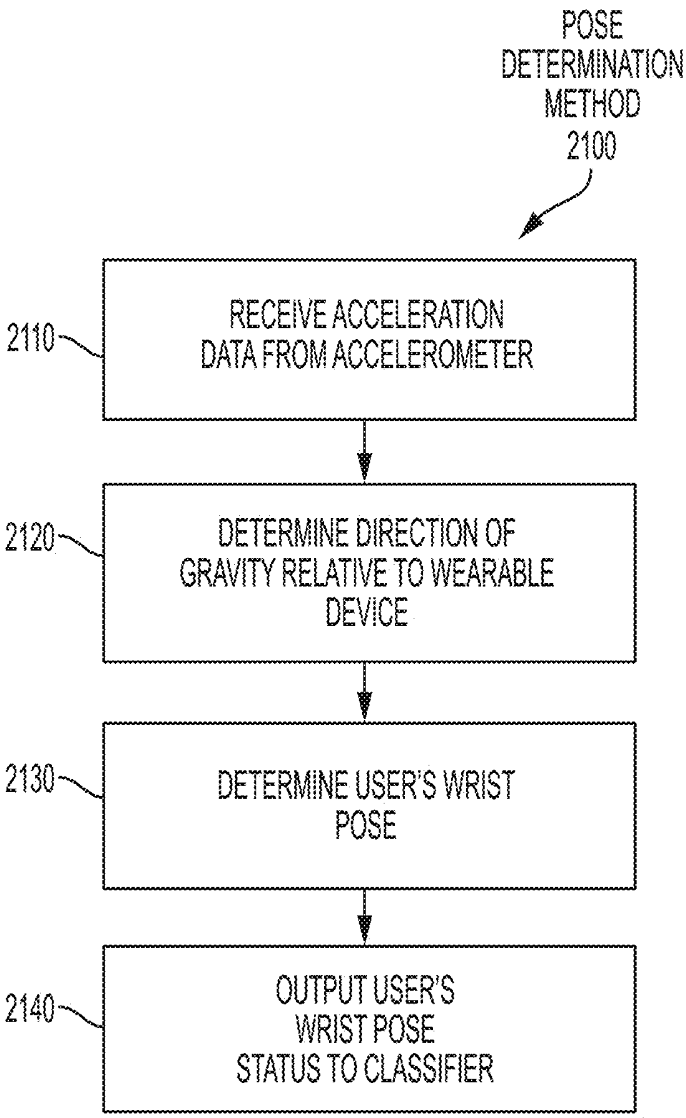

POSE DETERMINATION METHOD 2100
2110
RECEIVE ACCELERATION DATA FROM ACCELEROMETER
2120
DETERMINE DIRECTION OF GRAVITY RELATIVE TO WEARABLE DEVICE
2130
DETERMINE USER'S WRIST POSE
2140
OUTPUT USER'S WRIST POSE STATUS TO CLASSIFIER

FIG. 21

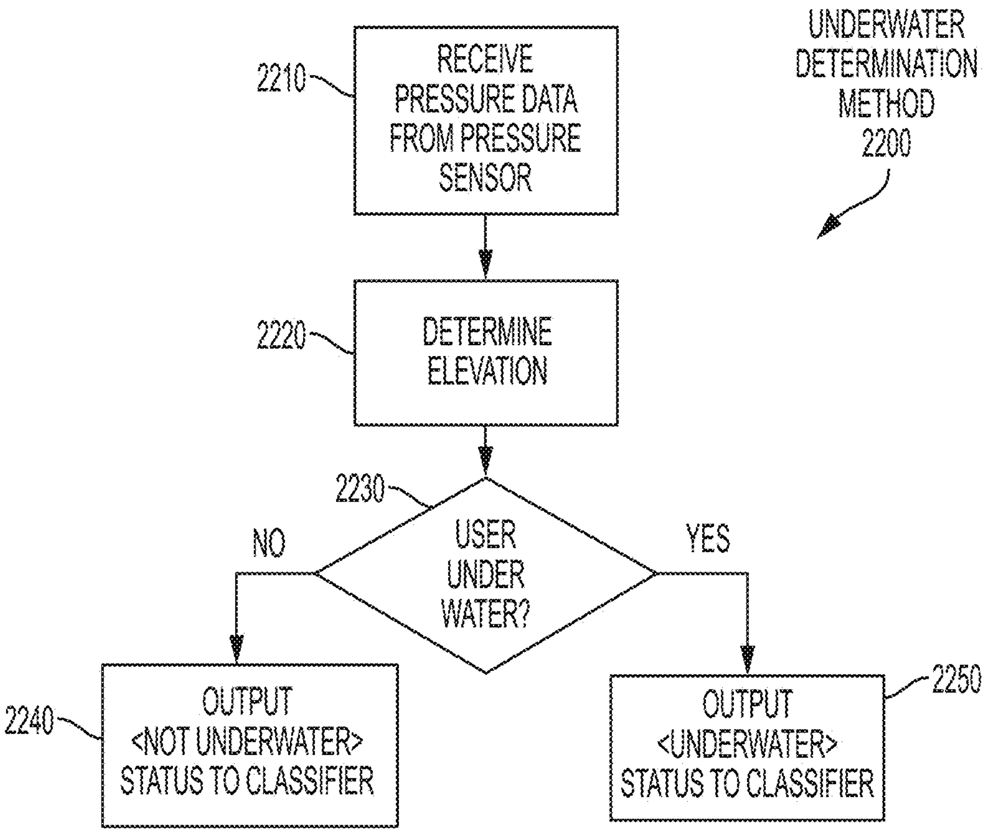

UNDERWATER DETERMINATION METHOD 2200
2210
RECEIVE PRESSURE DATA FROM PRESSURE SENSOR
2220
DETERMINE ELEVATION
2230
USER UNDER WATER?
NO
YES
2240
OUTPUT <NOT UNDERWATER> STATUS TO CLASSIFIER
2250
OUTPUT <UNDERWATER> STATUS TO CLASSIFIER

FIG. 22

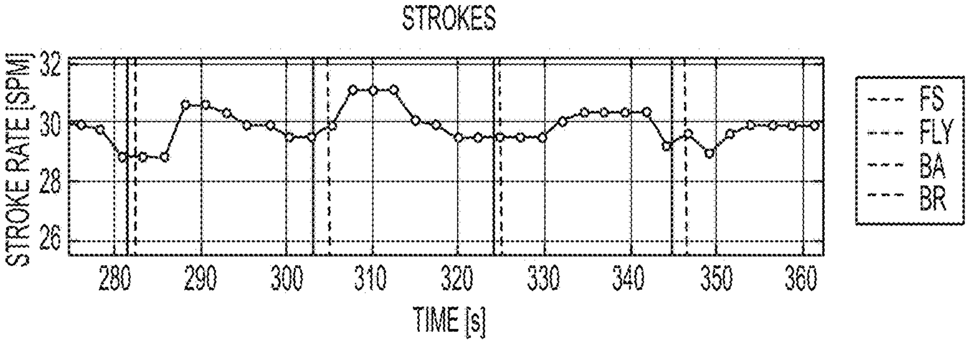


FIG. 23A

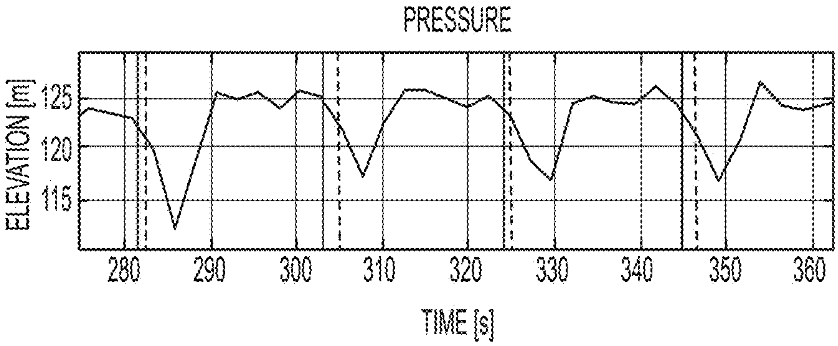


FIG. 23B

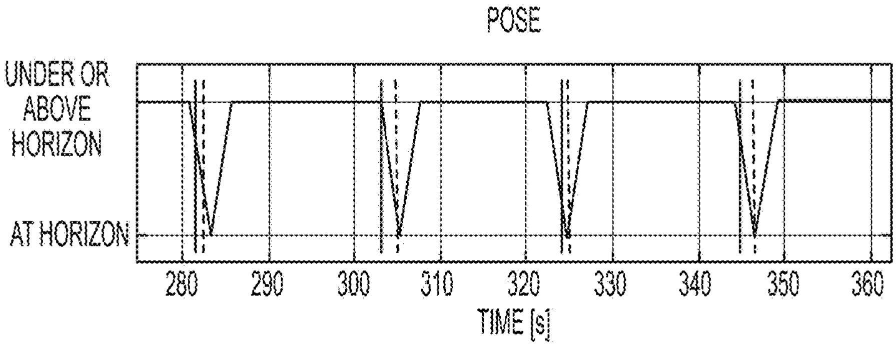


FIG. 23C

SYSTEMS AND METHODS OF SWIMMING CALORIMETRY

PRIORITY CLAIM

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/382,060, titled "System and Methods for Swimming Calorimetry," which was filed on Aug. 31, 2016 and is incorporated by reference herein in its entirety.

[0002] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/478,900, titled "Swimming Glide Detection," which was filed on Mar. 30, 2017 and is incorporated by reference herein in its entirety.

CROSS-REFERENCE TO RELATED APPLICATIONS

[0003] This application relates to co-pending U.S. patent application Ser. No. 15/,691,245 (Attorney Docket No.: 337722-628001), titled "Systems and Methods for Determining Swimming Metrics," which is filed on Aug. 30, 2017 and is incorporated by reference herein in its entirety.

[0004] This application related to co-pending U.S. patent application Ser. No. ______ (Attorney Docket No.: 337722-630001), titled "Systems and Methods of Swimming Analysis," which is filed on______ and is incorporated by reference herein in its entirety.

FIELD

[0005] The present disclosure relates generally to swimming calorimetry.

BACKGROUND

[0006] When a user is swimming, there is often a need to know many factors related to the swimming session, such as total distances, number of laps, swimming styles, stroke consistency, and/or energy expenditure. It is, however, generally difficult to estimate how many calories a user burns during a swimming session because energy expenditure depends on many factors such as speed, efficiency, swimming style, etc. Particularly, glides and strokes can correspond to different energy consumption rates, and ignoring glides can cause overestimates in energy expenditure. Accordingly, it is desirable to provide methods and systems for estimating energy expenditure of a user while swimming.

SUMMARY

[0007] The present disclosure relates to a method for improving an accuracy of a wearable device while estimating energy expenditure of a user during a swimming session. In some embodiments, the method can include: collecting, by a motion sensing module of a wearable device, motion data of the user; determining, by a processor circuit of the wearable device, rotational data of the user based on the motion data; counting, by the processor circuit, a number of strokes made by the user based on the set of rotational data; estimating, by the processor circuit, a stroke rate of the user based on the number of strokes; counting, by the processor circuit, a number of laps finished by the user based on the set of rotational data; calculating, by the processor circuit, a stroke length based on the number of strokes, the number of laps finished, and a lap length associated with the swimming session; calculating, by the processor circuit, a speed of the user based on the stroke rate and the stroke length; estimating, by the processor circuit, an efficiency of the user based on at least one of the stroke length or a level of stroke orbit consistency of the user; classifying, by the processor circuit, a swimming style of the user based on the set of rotational data; determining, by the processor circuit, an energy expenditure of the user based on the speed, efficiency, and swimming style of the user; and outputting, by the processor circuit, the determined energy expenditure of the user. In some embodiments, the motion data can be expressed in a first frame of reference and the rotation data can be expressed in a second frame of reference.

[0008] In some embodiments, the method can include receiving one or more inputs form the user; adjusting the energy expenditure of the user based on the received one or more inputs; and outputting the adjusted energy expenditure of the user. In some embodiments, the one or more inputs from the user can include at least one of the user's gender, age, height, weight, or body mass index.

[0009] In some embodiments, the method can include measuring, by a heart rate sensing module of the wearable device, a heart rate of the user; determining a fraction of heart rate reserve (FHR) of the user based on the measured heart rate; estimating, by the processor circuit, the user's anaerobic energy expenditure based on at least one of the user's fraction of heart rate reserve, stroke length, stroke rate, and or speed; and determining, by the processor circuit, the energy expenditure of the user based on the estimated anaerobic energy expenditure.

[0010] In some embodiments, the method can include: measuring, by a heart rate sensing module of the wearable device, a heart rate of the user; determining, by the processor circuit, a fraction of heart rate reserve (FHR) of the user based on the measured heart rate; determining, by the processor circuit, a maximal oxygen uptake of the user; determining, by the processor circuit, a heart rate model based on FHR and the maximal oxygen uptake, wherein determining the energy expenditure of the user based on the heart rate model.

[0011] In some embodiments, the method can include: receiving, by a GPS sensor of the wearable device, location data of the user during the swimming session; and calculating, by the processor circuit, a stroke length and a speed of the user based on the received location data. In some embodiments, the motion sensing module can include at least one of a gyroscope or an accelerometer.

[0012] In some embodiments, the method can include: detecting, by the processor circuit, one or more glides of the user during the swimming session; and determining, by the processor circuit, the energy expenditure of the user based on the detected one or more glides. In some embodiments, the method can include: determining, by the processor circuit, whether the user is making a turn based on the set of rotational data; detecting, by the processor circuit, a pose angle of the user's wrist based on the set of rotational data; determining, by the processor circuit, whether the user is under water using pressure data received from a pressure sensor of the wearable device; detecting, by the processor circuit, one or more glides of the user based on the stroke rate, the pose angle of the user's wrist, whether the user is making a turn, and whether the user is under water.

[0013] In some embodiments, the method can include: determining, by the processor circuit, a direction of gravity

relative to the user device based on the motion data; detecting, by the processor circuit, a pose of the user's wrist based on the direction of gravity.

[0014] In some embodiments, the method can include: receiving, by the processor circuit, pressure data from a pressure sensor of the wearable device; determining, by the processor circuit, an elevation of the wearable device based on the pressure data; and determining, by the processor circuit, whether the user is under water based on the determined elevation.

[0015] The present disclosure also relates to a system for improving an accuracy of a wearable device while estimating energy expenditure of a user during a swimming session. In some embodiments, the system can include: a motion sensing module configured to collect motion data of the user; a processor circuit in communication with the motion sensing module and configured to execute instructions causing the processor circuit to: determine rotational data of the user base on the motion data; count a number of strokes made by the user based on the set of rotational data; estimate a stroke rate of the user based on the number of strokes; count a number of laps finished by the user based on the set of rotational data; estimate a stroke length based on the number of strokes, the number of laps, and a length associated with the swimming session; estimate a speed of the user based on the stroke rate and the stroke length; estimate efficiency of the user based on at least one of the stroke length or a level of stroke orbit consistency of the user; classify a swimming style of the user based on the set of rotational data; determine an energy expenditure of the user based on the speed, efficiency, and swimming style of the user; and output the determined energy expenditure of the user.

[0016] In some embodiments, the system can include a heart rate sensing module configured to measure a heart rate of the user. In some embodiments, the instructions can further cause the processor circuit to: determine, a fraction of heart rate reserve (FHR) of the user based on the measured heart rate; determine, a maximal oxygen uptake of the user; determine, a heart rate model based on the FHR and the maximal oxygen uptake; and determine the energy expenditure of the user based on the heart rate model.

[0017] Other features and advantages will become apparent from the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Various objects, features, and advantages of the present disclosure can be more fully appreciated with reference to the following detailed description of the present disclosure when considered in connection with the following drawings, in which like reference numerals identify like elements.

[0019] FIG. **1** illustrates a wearable device according to some embodiments of the present disclosure.

[0020] FIG. **2** illustrates a block diagram of a wearable device according to some embodiments of the present disclosure.

[0021] FIG. **3** illustrates a companion device according to some embodiments of the present disclosure.

[0022] FIG. **4** illustrates a method of determining rotational data of a user while swimming according to some embodiments of the present disclosure.

[0023] FIGS. **5**A-**5**D illustrate an example of a body-fixed frame of reference according to some embodiments of the present disclosure.

[0024] FIG. **6** illustrates a set of rotational data of a wearable device in a body-fixed frame of reference according to some embodiments of the present disclosure.

[0025] FIG. **7** illustrates an example of an inertial frame of reference according to some embodiments of the present disclosure.

[0026] FIGS. **8**A-**8**D illustrate an example of an inertial frame of reference according to some embodiments of the present disclosure.

[0027] FIG. **9** illustrates a set of rotational data of a wearable device in an inertial frame of reference according to some embodiments of the present disclosure.

[0028] FIG. **10** illustrates a method of estimating energy expenditure of a user while swimming according to some embodiments of the present disclosure.

[0029] FIG. **11** illustrates a method of determining a direction of gravity according to some embodiments of the present disclosure.

[0030] FIG. **12** illustrates a method of determining a direction of gravity according to some embodiments of the present disclosure.

[0031] FIG. **13** illustrates percentage of aerobic and anaerobic contributions to user's total energy expenditure while swimming according to some prior published research.

[0032] FIG. **14** illustrates a user's energy expenditure as a function of swimming speed according to some prior published research.

[0033] FIG. **15** illustrates the relationship between the user's lactate concentration and the user's FHR according to some embodiments of the present disclosure.

[0034] FIG. **16** shows plot of total metabolic equivalent of task (METs) vs. speed, according to some embodiments of the present disclosure.

[0035] FIG. **17** illustrates a method of estimating energy expenditure of a user in open water according to some embodiments of the present disclosure.

[0036] FIG. **18** is a plot of normalized METs vs. fractional heart rate, according to some embodiments of the present disclosure.

[0037] FIG. **19** illustrates a method of detecting glides of a user while the user is swimming according to some embodiments of the present disclosure.

[0038] FIG. **20** illustrates a method of determining if a user is making a turn and the user's stroke rate according to some embodiments of the present disclosure.

[0039] FIG. **21** illustrates a method of determining a pose of a user's wrist according to some embodiments of the present disclosure.

[0040] FIG. **22** illustrates a method of determining if a user is under water according to some embodiments of the present disclosure.

[0041] FIGS. **23**A-**23**C show plots of stroke rate, pressure, and pose information of an example user's swimming session according to some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0042] In the following description, numerous specific details are set forth regarding the systems, methods and media of the present disclosure and the environment in which such systems, methods and media may operate, etc., in order to provide a thorough understanding of the present disclosure. It will be apparent to one skilled in the art, however, that the present disclosure may be practiced without such specific details, and that certain features, which are well known in the art, are not described in detail in order to avoid complication of the present disclosure. In addition, it will be understood that the examples provided below are exemplary, and that it is contemplated that there are other systems, methods, and media that are within the scope of the present disclosure.

[0043] The present disclosure describes a wearable device (or a "user device") that may be configured to determine consistency of a user's stroke orbits while the user is swimming. The wearable device can include one or more motion sensors to collect data about the wearable device's position and orientation in space and to track changes to the wearable device's position and orientation over time. Because a user can wear the wearable device, the motion information can provide information about the user's movements. For example, when a user is swimming, the user's arms are typically swinging along a particular path and at a particular frequency. If the user wears the wearable device on the user's wrist, the wearable device may be able to infer that the user is swimming in a certain style and/or changing in direction by sensing the way the user's arm moves in a certain path. When the user is swimming, there is a fairly periodic motion of the user's arm/wrist that can be tracked by the wearable device. For example, the user may take a breath every stroke, or every suitable number of strokes (e.g., every two strokes, every three strokes, every four strokes, etc.)

[0044] FIG. **1** shows an example of a wearable device (or a "user device") **100** according to some embodiments of the present disclosure. In some embodiments, wearable device **100** may be any suitable wearable device, such as a watch and/or a fitness band configured to be worn around an individual's wrist. In some embodiments, wearable device **100** includes a crown **120**, a band **140**, and/or a display surface **160**.

[0045] FIG. **2** depicts a block diagram of exemplary components that may be found within wearable device **100** according to some embodiments of the present disclosure. In some embodiments, wearable device **100** can include a main processor **210** (or "application processor"), a motion co-processor **215**, a memory **220**, one or more motion sensors **240**, a display **270**, an interface **280**, and a heart rate sensor **290**. Wearable device **100** may include additional modules, fewer modules, or any other suitable combination of modules that perform any suitable operation or combination of operations.

[0046] In some embodiments, main processor **210** can include one or more cores and can accommodate one or more threads to run various applications and modules. Software can run on main processor **210** capable of executing computer instructions or computer code. Main processor **210** can also be implemented in hardware using an application specific integrated circuit (ASIC), programmable logic array (PLA), field programmable gate array (FPGA), or any other integrated circuit.

[0047] In some embodiments, wearable device **100** also includes motion co-processor **215** which may draw less power than the main processor **210**. Whereas the main processor **210** may be configured for general purpose computations and communications, the motion co-processor **215** may be configured to perform a relatively limited set of tasks, such as receiving and processing data from motion sensor **240**, heart rate sensor **290**, and other modules within the wearable device **100**. In many embodiments, the main processor **210** may be powered down at certain times to conserve power, while the motion co-processor **215** remains powered on. Thus, the motion co-processor **215** is sometimes referred to as an "always-on" processor (AOP). Motion co-processor **215** may control when the main processor **210** is powered on or off.

[0048] Memory **220** can be a non-transitory computer readable medium, flash memory, a magnetic disk drive, an optical drive, a programmable read-only memory (PROM), a read-only memory (ROM), or any other memory or combination of memories. Memory **220** can include one or more modules **230**.

[0049] Main processor **210** or motion co-processor **215** can be configured to run module **230** stored in memory **220** that is configured to cause main processor **210** or motion co-processor **215** to perform various steps that are discussed throughout the present disclosure.

[0050] In some embodiments, wearable device **100** can include one or more motion sensors **240**. For example, motion sensors **240** can include a gyroscope **250** and an accelerometer **260**. In some embodiments, accelerometer **260** may be a three-axis accelerometer that measures linear acceleration in up to three-dimensions (for example, x-axis, y-axis, and z-axis). In some embodiments, gyroscope **250** may be a three-axis gyroscope that measures rotational data, such as rotational movement and/or angular velocity, in up to three-dimension (for example, yaw, pitch, and roll). In some embodiments, accelerometer **260** may be a microelectromechanical system (MEMS) accelerometer, and gyroscope **250** may be an MEMS gyroscope. Main processor **210** or motion co-processor **215** of wearable device **100** may receive motion information from one or more motion sensors **240** to track acceleration, rotation, position, or orientation information of wearable device **100** in six degrees of freedom through three-dimensional space.

[0051] In some embodiments, wearable device **100** may include other types of sensors in addition to accelerometer **260** and gyroscope **250**. For example, wearable device **100** may include an altimeter or barometer, or other types of location sensors, such as a GPS sensor.

[0052] Wearable device **100** may also include display **270**. Display **270** may be a screen, such as a crystalline (e.g., sapphire) or glass touchscreen, configured to provide output to the user as well as receive input from the user via touch. For example, display **270** may be configured to display a current heart rate or daily average energy expenditure. Display **270** may receive input from the user to select, for example, which information should be displayed, or whether the user is beginning a physical activity (e.g., starting a session) or ending a physical activity (e.g., ending a session), such as a swimming session, a running session, or a cycling session. In some embodiments, wearable device **100** may present output to the user in other ways, such as by producing sound with a speaker (not shown), and wearable device **100** may receive input from the user in other ways, such as by receiving voice commands via a microphone (not shown).

[0053] In some embodiments, wearable device **100** may communicate with external devices via interface **280**, including a configuration to present output to a user or receive input from a user. Interface **280** may be a wireless interface. The wireless interface may be a standard Bluetooth (IEEE 802.15) interface, such as Bluetooth v4.0, also known as "Bluetooth low energy." In other embodiments, the interface may operate according to a cellphone network protocol such as Long Term Evolution (LTE) or a Wi-Fi (IEEE 802.11) protocol. In other embodiments, interface **280** may include wired interfaces, such as a headphone jack or bus connector (e.g., Lightning, Thunderbolt, USB, etc.).

[0054] Wearable device **100** can measure an individual's current heart rate from heart rate sensor **290**. Heart rate sensor **290** may also be configured to determine a confidence level indicating a relative likelihood of an accuracy of a given heart rate measurement. In other embodiments, a traditional heart rate monitor may be used and may communicate with wearable device **100** through a near field communication method (e.g., Bluetooth).

[0055] Wearable device **100** may be configured to communicate with a companion device **300** (FIG. **3**), such as a smartphone, as described in more detail herein. In some embodiments, wearable device **100** may be configured to communicate with other external devices, such as a notebook or desktop computer, tablet, headphones, Bluetooth headset, etc.

[0056] The modules described above are examples, and embodiments of wearable device **100** may include other modules not shown. For example, some embodiments of wearable device **100** may include a rechargeable battery (e.g., a lithium-ion battery), a microphone or a microphone array, one or more cameras, one or more speakers, a watchband, water-resistant casing or coating, etc. In some embodiments, all modules within wearable device **100** can be electrically and/or mechanically coupled together. In some embodiments, main processor **210** can coordinate the communication among each module.

[0057] FIG. **3** shows an example of a companion device **300** according to some embodiments of the present disclosure. Wearable device **100** may be configured to communicate with companion device **300** via a wired or wireless communication channel (e.g., Bluetooth, Wi-Fi, etc.). In some embodiments, companion device **300** may be a smartphone, tablet computer, or similar portable computing device. Companion device **300** may be carried by the user, stored in the user's pocket, strapped to the user's arm with an armband or similar device, placed in a mounting device, or otherwise positioned within communicable range of wearable device **100**.

[0058] In some embodiments, companion device **300** may include a variety of sensors, such as location and motion sensors (not shown). When companion device **300** is available for communication with wearable device **100**, wearable device **100** may receive additional data from companion device **300** to improve or supplement its calibration or calorimetry processes. For example, in some embodiments, wearable device **100** may not include a GPS sensor as opposed to an alternative embodiment in which wearable device **100** may include a GPS sensor. In the case where wearable device **100** may not include a GPS sensor, a GPS sensor of companion device **300** may collect GPS location information, and wearable device **100** may receive the GPS location information via interface **280** (FIG. **2**) from companion device **300**.

[0059] In another example, wearable device **100** may not include an altimeter or barometer, as opposed to an alternative embodiment in which wearable device **100** may include an altimeter or barometer. In the case where wearable device **100** may not include an altimeter or barometer, an altimeter or barometer of companion device **300** may collect altitude or relative altitude information, and wearable device **100** may receive the altitude or relative altitude information via interface **280** (FIG. **2**) from the companion device **300**.

[0060] In another example, wearable device **100** may receive motion information from companion device **300**. Wearable device **100** may compare the motion information from companion device **300** with motion information from one or more motion sensors **240** of wearable device **100**. Motion information such as data from accelerometer **260** and/or gyroscope **250** may be filtered (e.g. by a high-pass, low-pass, band-pass, or band-stop filter) in order to improve the quality of motion information. For example, a low-pass filter may be used to remove some ambient noise.

[0061] Wearable device **100** may use sensed and collected motion information to predict a user's activity. Examples of activities may include, but are not limited to, walking, running, cycling, swimming, etc. Wearable device **100** may also be able to predict or otherwise detect when a user is sedentary (e.g., sleeping, sitting, standing still, driving or otherwise controlling a vehicle, etc.) Wearable device **100** may use a variety of motion information, including, in some embodiments, motion information from a companion device.

[0062] Wearable device **100** may use a variety of heuristics, algorithms, or other techniques to predict the user's activity. Wearable device **100** may also estimate a confidence level (e.g., percentage likelihood, degree of accuracy, etc.) associated with a particular prediction (e.g., 90% likelihood that the user is running) or predictions (e.g., 60% likelihood that the user is running and 40% likelihood that the user is walking).

[0063] FIG. **4** shows a flow chart illustrating a process **400** of determining one or more breaths taken by a user while swimming according to some embodiments of the present disclosure. In some embodiments, the process **400** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. As described in more details below, in some embodiments, the process **400** can include three steps. At step **410**, wearable device **100** receives motion information from one or more motion sensors **240**. At step **420**, wearable device **100** determines a first set of rotational data of wearable device **100**. At step **430**, wearable device **100** converts the first set of rotational data into a second set of rotational data, where the second set of rotational data include pitch rotational data.

[0064] At step **410**, motion information may be received from one or more motion sensors **240** on wearable device **100**. In some embodiments, motion information may include three-dimensional rotational data of wearable device **100** from gyroscope **250**. In some embodiments, motion information may include three-dimensional accelerations of wearable device **100** from accelerometer **260**.

[0065] At step **420**, wearable device **100** may determine a first set of rotational data of wearable device **100** based on the motion information received from one or more motion sensors **240**. In some embodiments, the rotational data of wearable device **100** include how wearable device **100** rotates, such as angular position, angular velocity, and/or angular acceleration of wearable device **100**, with respect to a frame of reference. In some embodiments, if the rotational data of wearable device **100** is angular acceleration, then angular velocity and/or angular position can be obtained by integrating the angular acceleration over time. Likewise, if the rotational data of wearable device **100** is angular velocity, then angular position can be obtained by integrating the angular velocity over time. In some embodiments, the first set of rotational data is received from gyroscope **250** and is expressed in a body-fixed frame of reference with respect to wearable device **100**.

[0066] FIG. **5**A illustrates an example of a body-fixed frame of reference **500** according to some embodiments of the present disclosure. In FIG. **5**A, the rotational axes of body-fixed frame of reference **500** are with respect to wearable device **100**. For example, the z-axis is perpendicular to the display surface **160** of wearable device **100**. The x-axis and the y-axis can be chosen relatively arbitrarily as long as the three axes are perpendicular to each other. In FIG. **5**A, the x-axis is parallel with the direction pointed by crown **120** of wearable device **100**, and the y-axis is parallel with the direction of band **140** of wearable device **100** (assuming the direction pointed by crown **120** of wearable device **100** is perpendicular to the direction of band **140** of wearable device **100**).

[0067] FIG. **5**B-**5**D illustrates examples to express one or more orientations in body-fixed frame of reference **500** according to some embodiments of the present disclosure. In FIG. **5**B, an orientation/direction **510** has an angle (φ) **502** with respect to the positive x-axis, an angle (θ) **504** with respect to the positive y-axis, and an angle (ψ) **506** with respect to the positive z-axis. The direction **510** can be expressed in body-fixed frame of reference **500** as [cos(φ), cos(θ), cos(ψ)], which is a non-limiting example/format of the first set of rotational data. For example, direction **520** in FIG. **5**B is parallel with and pointing toward the positive x-axis, so the angle (φ) between direction **520** and the positive x-axis is 0 degree; the angle (θ) between direction **520** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **520** and the positive z-axis is 90 degrees. Therefore, direction **520** can be expressed as [cos(0), cos (90), cos(90)], which is [1, 0, 0]. As another example, direction **530** in FIG. **5**B is parallel with and pointing toward the positive z-axis, so the angle (φ) between direction **530** and the positive x-axis is 90 degrees; the angle (θ) between direction **530** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **530** and the positive z-axis is 0 degrees. Therefore, direction **530** can be expressed as [cos (90), cos(90), cos(0)], which is [0, 0, 1]. As yet another example, direction **540** represents direction of gravity in FIG. **5**B and is parallel with and pointing toward the negative y-axis, so the angle (φ) between direction **540** and the positive x-axis is 90-degrees; the angle (θ) between direction **540** and the positive y-axis is 180 degrees; and the angle (ψ) between direction **540** and the positive z-axis is 90 degrees. Therefore, direction **540** can be expressed as [cos (90), cos(180), cos(90)], which is [0, −1, 0].

[0068] In FIG. **5**C, wearable device **100** is held vertically. As discussed earlier, the x-axis is parallel with direction pointed by crown **120**, the y-axis is parallel with band **140**, and the z-axis is perpendicular to display surface **160**. Direction **550** in FIG. **5**C represents the direction pointed by crown **120**, so the angle (φ) between direction **550** and the positive x-axis is 0 degrees; the angle (θ) between direction **550** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **550** and the positive z-axis is 90 degrees. Therefore, direction **550** can be expressed as [cos(0), cos (90), cos(90)], which is [1, 0, 0]. As another example, direction **540** represents direction of gravity in FIG. **5**C and is parallel with and pointing toward the negative y-axis, so the angle (φ) between direction **540** and the positive x-axis is 90 degrees; the angle (θ) between direction **540** and the positive y-axis is 180 degrees; and the angle (ψ) between direction **540** and the positive z-axis is 90 degrees. Therefore, direction **540** in FIG. **5**C can be expressed as [cos(90), cos(180), cos(90)], which is [0, −1, 0].

[0069] In FIG. **5**D, wearable device **100** is rotated 45 degrees clockwise compared with FIG. **5**C. As discussed earlier, the x-axis is parallel with direction pointed by crown **120**, the y-axis is parallel with band **140**, and the z-axis is perpendicular to display surface **160**. Direction **550** in FIG. **5**D represents the direction pointed by crown **120**, so the angle (φ) between direction **550** and the positive x-axis is 0 degrees; the angle (θ) between direction **550** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **550** and the positive z-axis is 90 degrees. Therefore, direction **550** can be expressed as [cos(0), cos(90), cos(90)], which is [1, 0, 0]. As another example, direction **540** represents direction of gravity in FIG. **5**D. The angle (φ) between direction **540** and the positive x-axis is 45 degrees; the angle (θ) between direction **540** and the positive y-axis is 135 degrees; and the angle (ψ) between direction **540** and the positive z-axis is 90 degrees. Therefore, direction **540** in FIG. **5**D can be expressed as [cos(45), cos(135), cos(0)], which is [0.707, −0.707, 0].

[0070] It is noted that the expression of direction **550** is the same in FIG. **5**C and FIG. **5**D even though wearable device **100** has rotated. This is because the body-fixed frame of reference **500** is always fixed with respect to wearable device **100**. As a result, when the position of wearable device **100** changes, the three axes in body-fixed frame of reference **500** and direction **550** change too, and the relative position between direction **550** and the three axes remain the same. On the other hand, although the direction of gravity **540** does not change in an "absolute" sense, it does change its position relative to the wearable device **100**, when the wearable device **100** changes position. Therefore, the expression of gravity direction **540** does not stay fixed in the body-fixed frame of reference **500** when wearable device changes position.

[0071] FIG. **6** illustrates a first set of rotational data of wearable device **100** according to some embodiments of the present disclosure. Specifically, FIG. **6** illustrates estimation of the gravity in the body-fixed frame of reference **500**. The x-axis shows cos(φ) where φ is the angle between gravity and the positive x-axis in the body-fixed frame of reference **500**. The y-axis shows cos(θ), where θ is the angle between gravity and the positive y-axis in the body-fixed frame of reference **500**. The z-axis shows cos(ψ), where ψ is the angle between gravity and the positive z-axis in the body-fixed frame of reference **500**. For example, if the display surface of wearable device **100** faces up toward the sky, parallel with the ground, then the gravity direction can be expressed as [0, 0, −1]. As another example, if crown is pointed towards the ground, then the gravity direction can be expressed as [1, 0, 0]. Gravity estimation in body-fixed frame of reference can help indicate when wearable device **100** is making a pitch and/or roll movement. For example, as discussed above, when a user's wrist is in a position such that crown is pointed towards the ground, the gravity direction is [1, 0, 0]. If the user then pitches his or her wrist up for 90 degrees, then display surface of wearable device **100** faces up toward the sky, parallel with the ground, and the gravity direction is expressed as [0, 0, −1]. If the user then rolls his or her wrist up for 90 degrees, then crown of wearable device **100** faces up toward the sky, and the gravity direction is expressed as [−1, 0, 0]. These examples illustrate that gravity direction in the body-fixed frame of reference **500** can change in response to pitch and/or roll movement. In some embodiments, the gravity estimation in body-fixed frame of reference **500** can be used together with accelerometer **260** to estimate gravity. However, the gravity direction in the body-fixed frame of reference **500** does not change in response to yaw movement. For example, if the display surface of wearable device **100** is facing up toward the sky, parallel with the ground, then the gravity direction is expressed as [0, 0, −1.] If the user then makes a yaw movement along the horizontal plane, the gravity direction remains [0, 0, −1].

[0072] Also, as discussed above, because wearable device **100** is rotating with the body-fixed frame of reference **500**, the directions of wearable device **100** and components thereof are fixed. For example, no matter whether the crown is pointing up, straight, or down, the crown direction is always expressed in a body-fixed frame of reference **500** as [1, 0, 0]. Therefore, in some embodiments, it is more suitable to express the positions of wearable device **100** in a frame of reference that is not body-fixed in order to more readily indicate the movements of wearable device **100** with respect to external references.

[0073] At step **430**, wearable device **100** converts the first set of rotational data into a second set of rotational data. As described above, rotational data in the body-fixed frame of reference cannot readily indicate whether or not wearable device **100** undergoes movements with respect to external references. To address this issue, wearable device **100** converts the rotational data in the body-fixed frame of reference into rotational data in an inertial frame of reference using techniques appreciated by people skilled in the art such as the one discussed in "Kalman-filter-based orientation determination using inertial/magnetic sensors: observability analysis and performance evaluation," Angelo Maria Sabatini, published Sept. 27, 2011, Sensors 2011, 11, 9182-9206.

[0074] FIG. **7** illustrates an inertial frame of reference **700** according to some embodiments of the present disclosure. In FIG. **7**, the z-axis is based on the direction of gravity. The x-axis and the y-axis can be chosen relatively arbitrarily as long as the three axes are perpendicular to each other. The z-axis is also referred to as yaw axis because any yaw movement rotates around the z-axis. In some embodiments, the x-axis can indicate the direction of movements, and the x-axis can be referred to as roll axis because any roll movement rotates around the x-axis. And the y-axis can be referred to as pitch axis because any pitch movement rotates around the y-axis.

[0075] FIGS. **8**A-**8**D illustrate an example of an inertial frame of reference **800** according to some embodiments of the present disclosure. FIG. **8**A depicts inertial frame of reference **800** in a context where a user is swimming. In FIG. **8**A, the user wears wearable device **100**. But the z-axis (or the yaw axis) in the inertial frame of reference is based on the direction of gravity rather than the wearable device itself. Additionally, assuming the user is swimming laps, the x-axis (or the roll axis) is substantially parallel to the direction of the laps, and the y-axis (or the pitch axis) is perpendicular to the other two axes. In some embodiments, the x-axis (or the roll axis) and the y-axis (or the pitch axis) can be chosen relatively arbitrarily as long as the three axes are perpendicular to each other. In FIG. **8**A, the z-axis is also referred to as yaw axis because any yaw movement rotates around the z-axis. Similarly, the x-axis is also referred to as roll axis because any roll movement rotates around the x-axis. And the y-axis is also referred to as pitch axis because any pitch movement rotates around the y-axis. By knowing the difference between the three-axes in the fixed-body frame of reference **500** and the three-axis in the inertial frame of reference **800**, the rotational data expressed in the fixed-body frame of reference **500** can be converted into the rotational data expressed in the inertial frame of reference **800** using techniques appreciated by people skilled in the art such as the one discussed in Sabatini.

[0076] FIG. **8**B illustrates that wearable device **100** can make rotational movement with respect to inertial frame of reference **800**. In FIG. **8**B, an orientation/direction **810** has an angle (φ) **802** with respect to the positive x-axis, an angle (θ) **804** with respect to the positive y-axis, and an angle (ψ) **806** with respect to the positive z-axis. The direction **810** can be expressed in inertial frame of reference **800** as [cos(φ), cos(θ), cos(ψ)], which is a non-limiting example/format of the second set of rotational data.

[0077] FIGS. **8**C and **8**D illustrate how same orientations in FIGS. **5**C and **5**D can be expressed differently in inertial frame of reference **800**. In FIG. **8**C, wearable device **100** is held vertically, which is the same as FIG. **5**C. As discussed earlier, the z-axis is based on the gravity in inertial frame of reference **800**. In FIG. **8**C, the positive z-axis is chosen as the direct opposite position of gravity, the x-axis is perpendicular to the z-axis and pointing right horizontally, and the y-axis is perpendicular to both x-axis and y-axis and pointing "out" of FIG. **8**C. Direction **550** in FIG. **8**C represents the direction pointed by crown **120**, so the angle (φ) between direction **550** and the positive x-axis is 0 degree; the angle (θ) between direction **550** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **550** and the positive z-axis is 90 degrees. Therefore, direction **550** can be expressed as [cos(0), cos(90), cos(90)], which is [1, 0, 0]. As another example, direction **540** represents direction of gravity in FIG. **8**C and is parallel with and pointing toward the negative z-axis, so the angle (φ) between direction **540** and the positive x-axis is 90 degrees; the angle (θ) between direction **540** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **540** and the positive z-axis is 180 degrees. Therefore, direction **540** in FIG. **8**C can be expressed as [cos(90), cos(90), cos(180)], which is [0, 0, −1].

[0078] In FIG. **8**D, wearable device **100** is rotated 45 degrees clockwise compared with FIG. **8**C. Because the three axes are based on gravity, they can remain the same as FIG. **8**C. Direction **550** in FIG. **8**D represents the direction pointed by crown **120**, and the angle (φ) between direction **550** and the positive x-axis is 45 degrees; the angle (θ) between direction **550** and the positive y-axis is 90 degree; and the angle (ψ) between direction **550** and the positive z-axis is 135 degree. Therefore, direction **550** can be expressed as [cos(45), cos(90), cos(135)], which is [0.707, 0, −0.707]. As another example, direction **540** represents direction of gravity in FIG. **8**D. The angle (φ) between direction **540** and the positive x-axis is 90 degree; the angle (θ) between direction **540** and the positive y-axis is 90 degrees; and the angle (ψ) between direction **540** and the positive z-axis is 180 degrees. Therefore, direction **540** in FIG. **8**D can be expressed as [cos(90), cos(90), cos(180)], which is [0, 0, −1].

[0079] It is noted that the expression of gravity direction **540** is the same in FIG. **8**C and FIG. **8**D even though wearable device **100** has rotated. This is because the inertial frame of reference **800** is always fixed with respect to gravity. As a result, when position of wearable device **100** changes, the three axes in the inertial frame of reference **800** do not move. On the other hand, the direction **550** does move with respect to the three axes, so the expression of direction **550** can change in the inertial frame of reference **500** even though it is fixed in body-fixed frame of reference **500**.

[0080] FIG. **9** illustrates a first set of rotational data of wearable device **100** according to some embodiments of the present disclosure. Specifically, FIG. **9** illustrates estimation of crown direction in the inertial frame of reference **800** while a user is swimming laps. The x-axis shows cos(φ) where φ is the angle between crown direction and the positive x-axis in the inertial frame of reference **800**. The y-axis shows cos(θ), where θ is the angle between crown direction and the positive y-axis in the inertial frame of reference **800**. The z-axis shows cos(ψ), where w is the angle between crown direction and the positive z-axis in the inertial frame of reference **800**. For example, if the display surface of the wearable device **100** is facing up towards the sky, parallel with the ground, and the crown is pointed towards the positive x-axis, then the crown direction can be expressed as [1, 0, 0]. Further, if wearable device **100** is making yaw movements, and the crown changes direction to point towards the negative x-axis, then the crown direction can be expressed as [−1, 0, 0]. As another example, if the crown is pointed towards the ground, then the new crown direction can be expressed as [0, 0, 1]. The rotational data in FIG. **9** are largely divided into two clusters, **902** and **904**, because every time the user makes a turn, the angle φ between crown direction and the positive x-axis in the inertial frame of reference **800** changes substantially around 180 degrees. Therefore, the rotational data expressed in FIG. **9** (i.e., the data switching from cluster **902** to cluster **904**, or vice versa) can indicate that wearable device **200** is undergoing a steady-state change in the direction that the user is heading.

[0081] The present disclosure describes ways to estimate energy expenditure of a user while swimming. Generally, a user's energy expenditure while swimming can depend on one or more of the following factors: swimming style, skill level, stroke rate, stroke length, gender, body surface area, and/or body composition and distribution. In some embodiments, other relevant factors can also affect the user's energy expenditure.

[0082] FIG. **10** illustrates a flow chart illustrating a computerized process **1000** of determining a user's energy expenditure while swimming according to certain embodiments of the present disclosure. In some embodiments, the computerized process **1000** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed.

[0083] At step **1002**, wearable device **100** may detect each time the user makes a stroke. In some embodiments, wearable device **100** can only detect the strokes made by the arm wearing the wearable device **100**. In these embodiments, for every stroke detected, the user may make two strokes, and the metrics related to strokes can sometimes be adjusted accordingly.

[0084] At step **1004**, wearable device **100** may estimate stroke rate of the user. In some embodiments, the stroke rate is determined as the number of strokes per unit period, such as a minute. For example, if wearable device **100** detects **120** strokes in four minutes, then the stroke rate can be determined to be 120 strokes/4 minutes=30 stroke/min.

[0085] At step **1006**, wearable device **100** may detect each time the user finishes a lap.

[0086] At step **1008**, wearable device **100** may determine the length of the pool where the user swims, as described in co-pending U.S. patent application Ser. No. ______ (Attorney Docket No.: 337722-628001), titled "Systems and methods for determining swimming metrics", which is incorporated by reference herein by its entirety.

[0087] At step **1010**, wearable device **100** may estimate stroke length of the user. In some embodiments, the stroke length is determined as the length per stroke. For example, if wearable device **100** detects that the user finishes four laps with each lap 50 meters, and wearable device **100** detects the user makes 100 strokes in the four laps, then wearable device **100** can determine the stroke length as 50 meters/lap*4 laps/100 strokes=2 meter/stroke.

[0088] At step **1012**, wearable device **100** may estimate the speed of the user. In some embodiments, wearable device **100** estimates the speed of the user based on the user's stroke rate and stroke length. The user's speed can be determined as stroke rate*stroke length. For example, if wearable device **100** detects that the user finishes four laps with each lap 50 meters in five minutes, and wearable device **100** detects that the user makes 100 strokes in the four laps, then as described above, wearable device **100** can determine the stroke length as 50 meters/lap*4 laps/100 strokes=2 meter/stroke and the stroke rate as 100 strokes/4 minutes=25 stroke/min. Then the speed can be determined as stroke length*stroke rate=2 meter/stroke*25 strokes/min=50 meter/min. In some embodiments, the speed of the user can also be determined by one or more sensors of wearable device **100**.

[0089] At step **1014**, wearable device **100** may estimate the user's efficiency. In some embodiments, wearable device **100** estimates the user's efficiency based on two factors. One factor is the user's stroke length. In general, the longer the user's stroke length, the higher the user's efficiency. Another factor is the user's stroke orbit consistency. In general, high stroke orbit consistency indicates high efficiency. Systems and methods for determining stroke orbit consistency are described in co-pending U.S. patent application Ser. No.______ (Attorney Docket No.: 337722-630001) titled "Systems and methods of swimming analysis", which is incorporated by reference herein in its entirety.

[0090] At step **1016**, wearable device **100** may classify the user's swimming style. In some embodiments, wearable device **100** can classify the user's swimming style as one of the following styles: breaststroke, backstroke, freestyle, butterfly, or unknown. Systems and methods for classifying swimming strokes are also described in co-pending U.S. patent application Ser. No.______ (Attorney Docket No.:

337722-630001) titled "Systems and methods of swimming analysis", which is incorporated by reference herein in its entirety.

[0091] At step **1018**, wearable device **100** may receive one or more inputs from the user. In some embodiments, wearable device **100** can receive user's gender. In some cases, female users can have more body fat than male users. Users with more body fat are more buoyant and as a result expend less energy. In some embodiments, wearable device **100** can receive other information regarding the user, such as the user's height and weight. In some embodiments, wearable device **100** can calculate the user's body mass index based on the user's height and weight, which measures a user's body fat and can be used to calculate a swimmer's buoyancy and energy expenditure.

[0092] At step **1020**, wearable device **100** may select an energy expenditure model based on information provided in step **1016** and/or step **1018**. For example, if wearable device **100** determines the user is swimming in freestyle, it will choose a model corresponding to freestyle. In some embodiments, once wearable device **100** selects an energy expenditure model based on the user's swimming style, it can further modify the model based on the gender.

[0093] At step **1022**, wearable device **100** may estimate the user's energy expenditure based on the user's speed, efficiency, and the selected model. In some embodiments, the user's energy expenditure can be expressed as the metabolic equivalent of task (MET). MET has unit of kcal/(kg*h), and **1** MET indicates the rate of energy spent per unit surface of a person during sitting.

[0094] FIG. **11** shows a method **1100** for determining a direction of gravity according to some embodiments of the present disclosure. The determined direction of gravity may be used to determine a frame of reference for motion information, such as rotational data, of wearable device **100**. In some embodiments, method **1100** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. Gravity determination method **1100** may begin at step **1110**

[0095] At step **1110**, wearable device **100** may receive motion information from the one or more motion sensors **240** on a wearable device (e.g., wearable device **100**) of a user. In some embodiments, motion information may include three-dimensional rotational information from one or more sensors **240** such as gyroscope **250** and three-dimensional acceleration information from one or more sensors **240** such as accelerometer **260**. In some embodiments, motion information may be filtered such as by a low-pass filter to remove unwanted noise from the ambient.

[0096] At step **1120**, wearable device **100** may determine the angular velocity of wearable device **100** with respect to a frame of reference such as a body-fixed frame of reference or an inertial frame of reference.

[0097] At step **1130**, wearable device **100** may determine whether the angular velocity of wearable device **100** determined at step **1120** is below a threshold. For example, the threshold may be approximately 0.05 radians per second, 0.2 radians per second, or 0.5 radians per second, etc. If the angular velocity exceeds the threshold (e.g., when the user is doing exercise), wearable device **100** may return to step **510**. In some embodiments, wearable device **100** may pause or wait for a period of time (e.g., 1 second, 5 seconds, 1 minute, etc.) before proceeding at step **1110**.

[0098] If the angular velocity is below the threshold (e.g., when the user is relatively still), wearable device **100** may proceed to step **1140**. In some embodiments, at step **1130** wearable device **100** may determine if the magnitude of forces acting on wearable device **100** are approximately equal to the normal force of gravity (1G) before proceeding to step **1140**. If the magnitude is not approximately the normal magnitude, wearable device **100** may also return to block **1110**. Wearable device **100** may estimate the direction of gravity when the angular velocity is below the threshold (e.g., when the user is relatively still) to avoid or reduce interference of confusion from acceleration due to other movements. Hypothetically, if wearable device **100** is having a 1 g acceleration along x-axis, then wearable device **100** may incorrectly determine the direction of gravity.

[0099] At step **1140**, wearable device **100** may estimate the direction of gravity relative to wearable device **100**. For example, in some embodiments, when wearable device **100** is held relatively still, accelerometer **260** within wearable device **100** may provide data about the direction of forces acting on wearable device **100**, which may be attributable primarily to gravity. In some embodiments, wearable device **100** may determine whether the user wearing wearable device **100** is accelerating (e.g., speeding up or slowing down) or traveling at an approximately constant velocity so as to further improve the estimate of the direction of gravity.

[0100] In some embodiments, wearable device **100** may end gravity determination method **1100** after outputting the estimated direction of gravity. In other embodiments, wearable device **100** may return to step **1110** to refine or otherwise repeat the method of estimating the direction of gravity relative to the wearable device.

[0101] FIG. **12** shows a method **1200** for determining a direction of gravity according to some embodiments of the present disclosure. In some embodiments, the method **1200** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. Gravity determination method **1200** can be used when the user has companion device **300** and may begin at step **1210**.

[0102] At step **1210**, wearable device **100** may periodically or continuously check for the presence of a companion device (e.g., companion device **300**). For example, in some embodiments, wearable device **100** may determine whether a connection (e.g., Bluetooth, IEEE 802.11 Wi-Fi, or other wireless or wired communication channel) has been established or may be established with companion device **300**. If the companion device **300** is present, wearable device **100** and/or companion device **300** may proceed to step **1220**.

[0103] At step **1220**, wearable device **100** and/or companion device **300** may estimate the direction of gravity relative to companion device **300**. In some embodiments, in contrast to the gravity determination method **1100**, it may not be necessary to check whether the angular velocity of companion device **300** is below a threshold because most or all of rotation of the angular velocity of companion device **300** may be orthogonal to the direction of gravity.

[0104] At step **1230**, wearable device **100** and/or companion device **300** may output the direction of gravity relative to companion device **300**. In some embodiments, the direction of gravity relative to companion device **300** may be combined or otherwise compared with the direction of gravity relative to wearable device **100**. In some embodiments, companion device **300** may further determine a rotation rate around the direction of gravity relative to the companion device and output the rotation rate instead of or in addition to the direction of gravity relative to companion device **300**.

[0105] In some embodiments, wearable device **100** and/or companion device **300** may end gravity determination method **1200** after outputting the estimated direction of gravity. In other embodiments, wearable device **100** and/or companion device **300** may return to step **1210** to refine or otherwise repeat the method of estimating the direction of gravity relative to the wearable device.

[0106] In some embodiment, the process **1000** also considers anaerobic contribution when estimating the user's overall energy expenditure. During high intensity workouts such as swimming, the anaerobic component plays an important role in the total energy expenditure.

[0107] For example, FIG. **13** illustrates percentage of aerobic and anaerobic contributions to user's total energy expenditure while swimming according to some prior published research. FIG. **13** is adapted from data by Hermansen and Karlsson (1967) and Houston (1978). In FIG. **13**, the x-axis shows the duration of the swimming workout expressed in minutes, and the y-axis shows the percentage of total energy expenditure. FIG. **13** shows that when the user swims for a short time (e.g., less than four minutes), the anaerobic contribution to energy expenditure is more dominant. And when the user swims for a longer time, the aerobic component becomes more dominant.

[0108] As another example, FIG. **14** illustrates a user's energy expenditure as a function of swimming speed according to some prior published research. FIG. **14** is adapted from Pendergast et al. (1978b). In FIG. **14**, the x-axis shows swimming speed, and the y-axis shows energy expenditure. The solid line and solid dots show the aerobic contribution to energy expenditure, and the dashed line and open dots show the anaerobic contribution to energy expenditure. FIG. **14** shows that when the user swims at a lower speed (e.g., less than 1.2 m/s), the aerobic component is more dominant. And when the user swims at a higher speed, the anaerobic component is more dominant.

[0109] Both FIG. **13** and FIG. **14** show that, in some cases, ignoring the anaerobic component could lead to inconsistent user experience and incorrect/underestimated calorie values.

[0110] There are several ways to modify the model shown in FIG. **10** to consider the anaerobic component of the user's energy expenditure. In some embodiments, the user's anaerobic energy expenditure can be estimated based on the user's fraction of heart rate reserve (FHR). FHR may be defined as the ratio of how close an individual's current heart rate is to his or her maximum heart rate (e.g., HRmax−HR) to the individual's heart rate range (e.g., HRmax−HRmin):

$$FHR=(HRmax-HR)/(HRmax-HRmin) \quad \text{(Eq. 1)}$$

[0111] FHR may range from 0 to 1 for any individual. When an individual's FHR is close to 0, it indicates that the user's heart rate is close to the individual's maximum heart rate. Similarly, when an individual's FHR is close to 1, it indicates that the individual's heart rate is close to the individual's minimum heart rate.

[0112] For example, FIG. **15** illustrates the relationship between the user's lactate concentration and the user's FHR according to some embodiments of the present disclosure. The x-axis shows the value of 1-FHR, and the y-axis shows the user's lactate concentration. FIG. **15** shows when the value of 1-FHR is greater than 0.7, the user's lactate concentration increases much faster. Because one's lactate concentration is positively related to one's anaerobic energy expenditure, when the value of 1-FHR is greater than 0.7, the user's anaerobic energy expenditure is more pronounced. When 1-FHR is greater than 0.7, FHR is less than 0.3, which means the user's heart rate is relatively close to his or her maximum heart rate. Therefore, in some embodiments, wearable device **100** can monitor the user's heart rate, and increase the estimation of energy expenditure in process **1000** to take the anaerobic contribution to energy expenditure into consideration based on the user's heart rate.

[0113] In some embodiments, wearable device **100** can estimate the user's anaerobic energy expenditure based one or more of the following factors about the user: stroke length, stroke rate, and/or speed.

[0114] FIG. **16** shows plot of total METs versus speed, according to some embodiments of the present disclosure. In FIG. **16**, the x-axis is the user's swimming speed in freestyle, and the y-axis is the user's METs estimated by the model shown in FIG. **10**. In FIG. **16**, each circle represents a sample. For example, circle **1616** represents a user with speed at around 0.6 m/s with stroke length around 1 m, and the estimated MET is around 14.8. FIG. **16** also plots some previously published research by others. For example, curve **1602** shows total METs versus speed for competitive swimmers, curve **1604** shows aerobic METs versus speed for competitive swimmers, curve **1606** shows total METs versus speed for recreational swimmers. FIG. **16** also shows regression models based on stroke length for all samples. For example, curve **1610** shows total METs versus speed estimated for a swimmer with stroke length of 0.5 m, curve **1610** shows total METs versus speed estimated for a swimmer with stroke length of 1.0 m, and curve **1610** shows total METs versus speed estimated for a swimmer with stroke length of 1.5 m. FIG. **16** shows that, in some embodiments, based on the user's speed, stroke length, and swimming style, wearable device **100** can estimate the user's energy expenditure such as METs.

[0115] While many swimmers swim in pools, swimmers competing in open water events or in triathlons often swim in open waters, for example, lakes, oceans and rivers. In these open environments, calculating energy expenditure for a particular swimming workout can be challenging. For example, because laps are not being counted in a set distance pool, distance estimates may be difficult. Even with the assistance of a global positioning system (GPS) it may be difficult to obtain an accurate GPS fix. Further, open water conditions result in unknown resistance to the swimmer, for example water currents, waves, and even varying water densities.

[0116] FIG. **17** illustrates a method of estimating energy expenditure of a user in open water according to some embodiments of the present disclosure. FIG. **17** is substantially similar to FIG. **10** above. However, FIG. **17** has the additional components/steps related to heart rate measurements and calculations: GPS odometer **1706**, GPS sensor fusion **1714**, VO_2max **1722**, fractional heart rate **1724**, heart rate reliability **1726** and heart rate model **1728**.

[0117] For example, in some embodiments, a GPS sensor can be used to improve the stroke length estimates from **1710** and also the speed calculations from **1712**. Accordingly, a more accurate work rate model for the swimming session can be created.

[0118] In some embodiments, data from a PPG heart rate sensor can also be used to provide a more accurate calorie determination. For example, as discussed in the co-pending U.S. patent application Ser. No. 15/466,397, titled "Techniques for Jointly Calibrating Load and Aerobic Capacity," the user's VO2max **1722** and fractional heart rate **1724** can be determined. Based on the user's VO2max **1722** and fractional heart rate **1724** and the work rate model **1720**, a heart rate reliability **1726** and then a heart rate can be determined. In some embodiments, heart rate measurements can be more reliable in segments with small motion artifacts, for example, during glides or at the end of a lap. Based on this information, a heart rate model can be created.

[0119] Once both the work rate model **1720** and the heart rate model **1728** have been determined, and accordingly, a reliability of each of the models is determined, the appropriate model can be selected at model selection **1730**. Model selection may depend upon errors in the stroke length, stroke rate, distance, and heart rate to determine which model is more accurate. Further, the models can be fused together to create a more accurate total of model of calorimetry.

[0120] Once the appropriate model for the swimming session has been determined, then the METs for that session also can be calculated.

[0121] FIG. **18** is a plot of normalized METs vs. fractional heart rate, according to some embodiments of the present disclosure. The y axis shows METs/VO2max from 0.0 to 1.2 and the x axis is 1-Fractional Heart rate from 0.2 to 1.2. This plot shows a linear relationship between METs, normalized to VO2max, and fractional heart rate.

[0122] One difficulty in estimating energy expenditure of a user while swimming is how to distinguish glides and strokes. Glide detection can help to achieve more accurate calorimetry. For example, glides can cover up to 25% of a lap distance for some swimmers, in particular, efficient, experienced swimmers. Therefore, ignoring glides could lead to overestimates in energy expenditure, because glides may correspond to lower energy expenditure rate (i.e., lower MET) compared to strokes.

[0123] Glide detection can also help with the classifications of swimming styles. Based on information related to glide times, stroke rates, stroke patterns, and times for turns, the user's movement can be assigned to different styles (e.g., freestyle stroke, breaststroke, backstroke, butterfly stroke, etc.)

[0124] Glide detection can also help to provide more accurate lap times to the user. If the wearable device **100** or the companion device **300** can determine if the user is gliding, or stroking, or turning, the lap time can then be broken up into different parts, e.g., turn time, glide time, and stroke time. In this way, the user can review the data and assess his or her performances in further detail.

[0125] FIG. **19** shows a method **1900** of detecting glides during swimming. In some embodiments, the detection method **1900** can use measurements data from a gyroscope **250** in the wearable device **100** (not shown). The gyroscope **250** may be a three-axis gyroscope that measures rotational data, such as rotational movement and/or angular velocity, in up to three-dimension (e.g., yaw, pitch, and roll). In some embodiments, the method **1900** can use measurements data from an accelerometer **260** in the wearable device **100**. The accelerometer **260** may be a three-axis accelerometer that measures linear acceleration in up to three dimensions (e.g., x-axis, y-axis, and z-axis). In some embodiments, the method **1900** can use measurements data from a pressure sensor **1930** (e.g., an altimeter or barometer) in the wearable device **100**. In some embodiments, wearable device **100** can include a classifier module **1940** (e.g., of the processor **210**) which may determine whether the user is gliding based on the measurements data.

[0126] In some embodiments, the gyroscope **250** can measure rotational data and can provide information related to a user's stroke rate **1911**. For example, during glides, a user usually does not stroke. Thus the angular velocity value measured by the gyroscope **250** may be smaller compared to angular velocity values measured during strokes. In some embodiments, the gyroscope **250** can provide information related to turns **1912**. For example, a small or close to zero angular velocity value can indicate the user is not making a turn. The information related to stroke rate **1911** and turns **1912** may be sent to the classifier **1940**.

[0127] In some embodiments, the accelerometer **260** can measure acceleration data and can provide information related to a pose **1913** of a user's wrist. For example, during gliding, the user usually keeps his or her wrists relatively still. Thus the direction of gravity remains relatively constant in the body-fixed frame of reference of the wearable device **100**. The pose of the user's wrist can be determined based on the gravity direction. The information related to pose **1913** may be sent to the classifier **1940**.

[0128] In some embodiments, the pressure sensor **1930** can measure pressure data and can provide information related to under water detection **1914**. For example, during gliding, the user usually keeps his or her hands and/or arms under water. Thus, the pressure sensor **1930** may sense higher pressure due to the pressure from the water, which generally will be greater than pressure from the air. If the pressure sensor **1930** includes an altimeter, it may show a drop in elevation. The information related to under water detection **1914** may be sent to the classifier **1940**. The under water detection **1914** can help to pick up spurious strokes while the user is not under water. For example, the user may walk around the pool or wipe hair, and the wearable device **100** may obtain rotational and acceleration data. However, the measurements by the pressure sensor **1930** may indicate the user may not be under water. Therefore, these strokes may not be regarded as swimming strokes.

[0129] In some embodiments, other methods can be used to detect if the user is under water. For example, wearable device **100** can have a pressure sensitive screen which can detect a pressure imposed on it. Based on the detected pressure, wearable device **100** and/or companion device **300** can determine if the user is under water. In some embodiments, wearable device **100** and/or companion device **300** can estimate a underwater depth based on the detected pressure.

[0130] In some embodiments, the classifier **1940** can determine whether or not the user is gliding based on the measurements data from one sensor or multiple sensors. The classifier **1940** can be a computer program executed by the processor in the wearable device **100** and/or the companion device **300** (not shown). The classifier **1940** can implement algorithms to classify the user's movements during a swimming session into different categories, e.g., glide **1941**, or not glide **1942**.

[0131] FIG. **20** shows a method **2000** for determining whether a user is making a turn and the user's stroke rate according to some embodiments of the present disclosure.

The user's turning status and stroke rate may be determined and used to detect if the user is gliding. In some embodiments, method **2000** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. In the example described herein, method **2000** is performed by processor **210** of wearable device **100**. However, in some embodiments, some or all steps may be performed by other elements (e.g., by a processor of a mobile device in communication with wearable device **100**). The method **2000** may begin at step **2010**.

[0132] At step **2010**, three-dimensional rotational information may be received at the main processor **210** or motion co-processor **215** from the gyroscope **250** on a wearable device (e.g., wearable device **100**) of a user. In some embodiments, rotational information may be filtered, such as by a low-pass filter, to remove unwanted noise from the ambient.

[0133] At step **2020**, main processor **210** may determine angular velocity of wearable device **100** with respected to a frame of reference such as a body-fixed frame of reference or an inertial frame of reference.

[0134] At step **2030**, main processor **210** may determine whether the user is making a turn from the angular velocity. If it is determined that the user is making a turn, the turn and stroke rate determination method **2000** may proceed to step **2040**. At step **2040**, the user's turning status may be outputted to the classifier of the processor **200** for further processing. The user's turning status may be one of the parameters the classifier uses to detect gliding.

[0135] If main processor **210** determines that the user is not making a turn, it may proceed to step **2050**. At step **2050**, the user's stroke rate can be determined based on the angular velocity collected from the gyroscope **250**. Then at step **2060**, the user's stroke rate may be outputted to the classifier for further processing. The user's stroke rate may be one of the parameters the classifier uses to detect gliding.

[0136] FIG. **21** shows a method **2100** for determining a pose of a user's wrist according to some embodiments of the present disclosure. The determined pose of the user's wrist may be used to detect gliding during swimming. In some embodiments, method **2100** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. In the example described herein, method **2100** is performed by main processor **210** of wearable device **100**. However, in some embodiments, some or all steps may be performed by other elements (e.g., by a processor of a mobile device in communication with wearable device **100**). Pose determination method **2100** may begin at step **2110**.

[0137] At step **2110**, three-dimensional acceleration information may be received at main processor **210** or motion co-processor **215** from the accelerometer **260** on a wearable device (e.g., wearable device **100**) of a user. In some embodiments, acceleration information may be filtered, such as by a low-pass filter, to remove unwanted noise from the ambient.

[0138] At step **2120**, main processor **210** or motion co-processor **215** may determine a direction of gravity relative to the wearable device **100** with respect to a frame of reference such as a body-fixed frame of reference or an inertial frame of reference.

[0139] At step **2130**, main processor **210** may determine the pose of the user's wrist from the acceleration information and the gravity direction. For example, the user's wrist may be in a position such that display surface of the wearable device **100** may faces up toward the sky, parallel with the ground.

[0140] At step **2140**, the pose information of the user's wrist may be outputted to the classifier of main processor **210** for further processing. The pose information may be one of the parameters the classifier uses to detect gliding.

[0141] FIG. **22** shows a method **2200** for determining if a user is under water according to some embodiments of the present disclosure. The determined under water status may be used to detect gliding during swimming. In some embodiments, method **2200** can be modified by, for example, having steps combined, divided, rearranged, changed, added, and/or removed. In the example described herein, method **2200** is performed by processor **210** of wearable device **100**. However, in some embodiments, some or all steps may be performed by other elements (e.g., by a processor of a mobile device in communication with wearable device **100**). Underwater determination method **2200** may begin at step **2210**.

[0142] At step **2210**, pressure information may be received at main processor **210** or motion co-processor **215** from a pressure sensor on a wearable device (e.g., wearable device **100**) of a user. In some embodiments, pressure information may be filtered, such as by a low-pass filter, to remove unwanted noise.

[0143] At step **2220**, main processor **210** may determine an elevation of the wearable device **100** based on the received pressure data.

[0144] At step **2230**, main processor **210** may determine if the user is under water. For example, if the elevation of the wearable device **100** has a sudden decrease, possibly due to additional pressure from water, main processor **210** may determine the user is under water. If it is determined that the user is not under water, the status may be outputted to the classifier for further processing at step **2240**. If it is determined that the user is under water, the status may be outputted to the classifier for further processing at step **2250**. The status may be one of the parameters the classifier uses to detect gliding.

[0145] FIGS. **23**A-**23**C show examples of measured data during a user's swimming session in a pool. The horizontal time axes in the three figures are synchronized. The dashed vertical lines mark the time when the user started from one end of the pool and the solid vertical lines mark the time when the user reached the other end of the pool. FIG. **23**A shows the stroke rates as a function of time. The decrease in the stroke rate may be attributed to glides because most of the user's motions may be full body undulations during glides. FIG. **23**B shows the measured elevation from the pressure sensor as a function of time. The elevation dips may correspond to glides because the user is under water during glides and the pressure increase leads to an observable decrease of elevation. As the user's hands exit the water, the pressure decreases and the elevation increases. FIG. **23**C shows the pose information as a function of time. The pose of the user's wrist during the glide undulations is mostly in line with the horizon and under or above horizon during the strokes.

[0146] It is to be understood that the present disclosure is not limited in its application to the details of construction and to the arrangements of the components set forth in the description or illustrated in the drawings. The present disclosure is capable of other embodiments and of being practiced and carried out in various ways. In addition, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

[0147] As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, systems, methods and media for carrying out the several purposes of the present disclosure. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present disclosure.

[0148] Although the present disclosure has been described and illustrated in the foregoing exemplary embodiments, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the details of implementation of the present disclosure may be made without departing from the spirit and scope of the present disclosure, which is limited only by the claims which follow.

What is claimed is:

1. A method for improving an accuracy of a wearable device while estimating energy expenditure of a user during a swimming session, the method comprising:

collecting, by a motion sensing module of a wearable device, motion data of the user;

determining, by a processor circuit of the wearable device, rotational data of the user based on the motion data;

counting, by the processor circuit, a number of strokes made by the user based on the set of rotational data;

estimating, by the processor circuit, a stroke rate of the user based on the number of strokes;

counting, by the processor circuit, a number of laps finished by the user based on the set of rotational data;

calculating, by the processor circuit, a stroke length based on the number of strokes, the number of laps finished, and a lap length associated with the swimming session;

calculating, by the processor circuit, a speed of the user based on the stroke rate and the stroke length;

estimating, by the processor circuit, an efficiency of the user based on at least one of the stroke length or a level of stroke orbit consistency of the user;

classifying, by the processor circuit, a swimming style of the user based on the set of rotational data;

determining, by the processor circuit, an energy expenditure of the user based on the speed, efficiency, and swimming style of the user; and

outputting, by the processor circuit, the determined energy expenditure of the user.

2. The method of claim **1**, wherein the motion data is expressed in a first frame of reference and the rotation data is expressed in a second frame of reference.

3. The method of claim **1**, comprising:

receiving, by the processor circuit, one or more inputs from the user, wherein the one or more inputs from the user comprise at least one of the user's gender, age, height, weight, or body mass index;

adjusting, by the processor circuit, the energy expenditure of the user based on the received one or more inputs; and

outputting, by the processor circuit, the adjusted energy expenditure of the user.

4. The method of claim **1**, comprising:

measuring, by a heart rate sensing module of the user wearable device, a heart rate of the user;

determining, by the processor circuit, a fraction of heart rate reserve (FHR) of the user based on the measured heart rate;

estimating, by the processor circuit, the user's anaerobic energy expenditure based on at least one of the FHR, the stroke length, the stroke rate, or the speed; and

determining, by the processor circuit, the energy expenditure of the user based on the estimated anaerobic energy expenditure.

5. The method of claim **1**, comprising:

measuring, by a heart rate sensing module of the wearable device, a heart rate of the user;

determining, by the processor circuit, a fraction of heart rate reserve (FHR) of the user based on the measured heart rate;

determining, by the processor circuit, a maximal oxygen uptake of the user; and

determining, by the processor circuit, a heart rate model based on FHR and the maximal oxygen uptake, wherein determining the energy expenditure of the user based on the heart rate model.

6. The method of claim **1**, wherein calculating the speed of the user comprises:

receiving, by a GPS sensor of the wearable device, location data of the user during the swimming session; and

calculating, by the processor circuit, a stroke length and a speed of the user based on the received location data.

7. The method of claim **1**, wherein the motion sensing module comprises at least one of a gyroscope or an accelerometer.

8. The method of claim **1**, comprising:

detecting, by the processor circuit, one or more glides of the user during the swimming session; and

determining, by the processor circuit, the energy expenditure of the user based on the detected one or more glides.

9. The method of claim **8**, wherein detecting the one or more glides of the user comprises:

determining, by the processor circuit, whether the user is making a turn based on the set of rotational data;

detecting, by the processor circuit, a pose angle of the user's wrist based on the set of rotational data;

determining, by the processor circuit, whether the user is under water using pressure data received from a pressure sensor of the wearable device; and

detecting, by the processor circuit, one or more glides of the user based on the stroke rate, the pose of the user's wrist, whether the user is making a turn, and whether the user is under water.

10. The method of claim **9**, wherein detecting a pose angle of the user's wrist comprises:

determining, by the processor circuit, a direction of gravity relative to the user device based on the motion data;

detecting, by the processor circuit, a pose angle of the user's wrist based on the direction of gravity.

11. The method of claim **9**, wherein determining whether the user is under water comprises:

determining, by the processor circuit, an elevation of the wearable device based on the pressure data; and

determining, by the processor circuit, whether the user is under water based on the determined elevation.

12. A system for improving an accuracy of a wearable device while estimating energy expenditure of a user during a swimming session, the system comprising:
a motion sensing module configured to collect motion data of the user;
a processor circuit in communication with the motion sensing module and configured to execute instructions causing the processor circuit to:
determine rotational data of the user base on the motion data;
count a number of strokes made by the user based on the set of rotational data;
estimate a stroke rate of the user based on the number of strokes;
count a number of laps finished by the user based on the set of rotational data;
estimate a stroke length based on the number of strokes, the number of laps finished, and a lap length associated with the swimming session;
estimate a speed of the user based on the stroke rate and the stroke length;
estimate efficiency of the user based on at least one of the stroke length or a level of stroke orbit consistency of the user;
classify a swimming style of the user based on the set of rotational data;
determine an energy expenditure of the user based on the speed, efficiency, and swimming style of the user; and
output the determined energy expenditure of the user.

13. The system of claim **12**, wherein the instructions further cause the processor circuit to:
receive one or more inputs from the user, wherein the one or more inputs from the user comprise at least one of the user's gender, age, height, weight, or body mass index;
adjust the determined energy expenditure of the user based on the received one or more inputs; and
output the adjusted energy expenditure of the user.

14. The system of claim **12**, further comprising a heart rate sensing module configured to measure a heart rate of the user.

15. The system of claim **14**, wherein the instructions further cause the processor circuit to:
determine, a fraction of heart rate reserve (FHR) of the user based on the measured heart rate; determine, a maximal oxygen uptake of the user;
determine, a heart rate model based on the FHR and the maximal oxygen uptake; and
determine, the energy expenditure of the user based on the heart rate model.

16. The system of claim **12**, further comprising a GPS sensor configured to receive location data of the user.

17. The system of claim **16**, wherein the instructions further cause the processor circuit to:
estimate a stroke length and a speed of the user based on the received location data of the user.

18. The system of claim **12**, wherein the motion sensing module comprises at least one of a gyroscope or an accelerometer.

19. The system of claim **12**, wherein the instructions further cause the processor circuit to:
determine whether the user is making a turn based on the set of rotational data;
detect a pose of the user's wrist based on the set of rotational data;
determine whether the user is under water based on pressure data received from a pressure sensor of the wearable device;
determine whether the user is gliding while swimming based on the stroke rate, the pose of the user's wrist, whether the user is making a turn, and whether the user is under water;
adjust the energy expenditure of the user based on the determined glide; and
output the adjusted energy expenditure of the user.

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摘要(译)

本公开涉及估计用户在游泳时的能量消耗的系统和方法。用户设备的处理器电路可以基于笔划速率和笔划长度来估计用户的速度。处理器电路可以估计用户的效率。处理器电路可以对用户的游泳风格进行分类。处理器电路可以基于速度，效率和风格来确定用户的能量消耗。处理器电路还可以检测用户的滑动并调节能量消耗。