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(54) **HUMAN ACTIVITY MONITORING DEVICE WITH ACTIVITY IDENTIFICATION**

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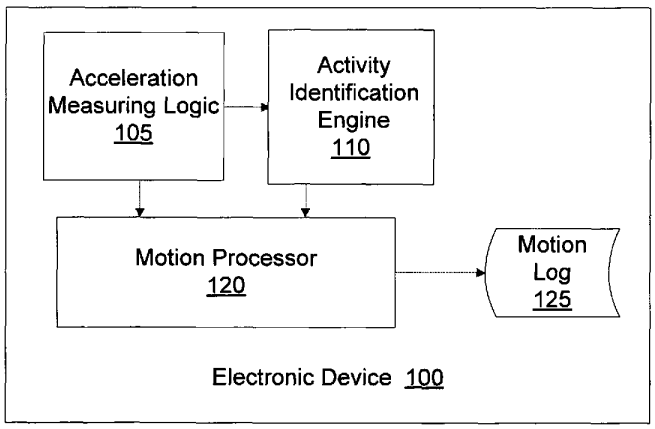
(57) **ABSTRACT**

A method or apparatus for monitoring human activity using an inertial sensor is described. The method includes monitoring accelerations, and identifying a current user activity from a plurality of user activities based on the accelerations. In one embodiment, each of the plurality of user activities is associated with one of a plurality of types of periodic human motions that are detectable by the portable electronic device, and wherein the identification of the current user activity is made based on detecting two or more instances of the periodic human motion associated with the user activity. The method further includes counting periodic human motions appropriate to the current user activity.

23 Claims, 14 Drawing Sheets



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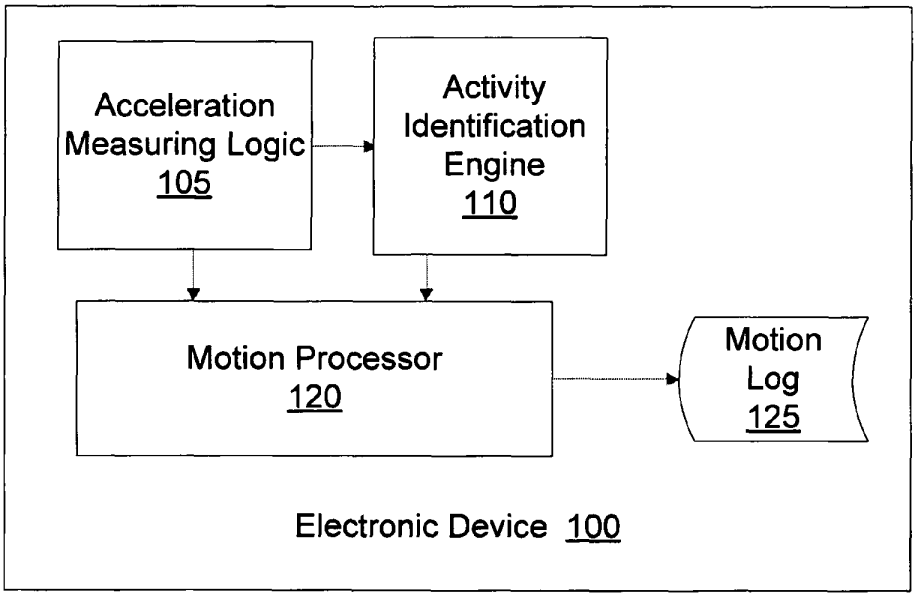
Acceleration Measuring Logic 105
Activity Identification Engine 110
Motion Processor 120
Motion Log 125
Electronic Device 100

Figure 1

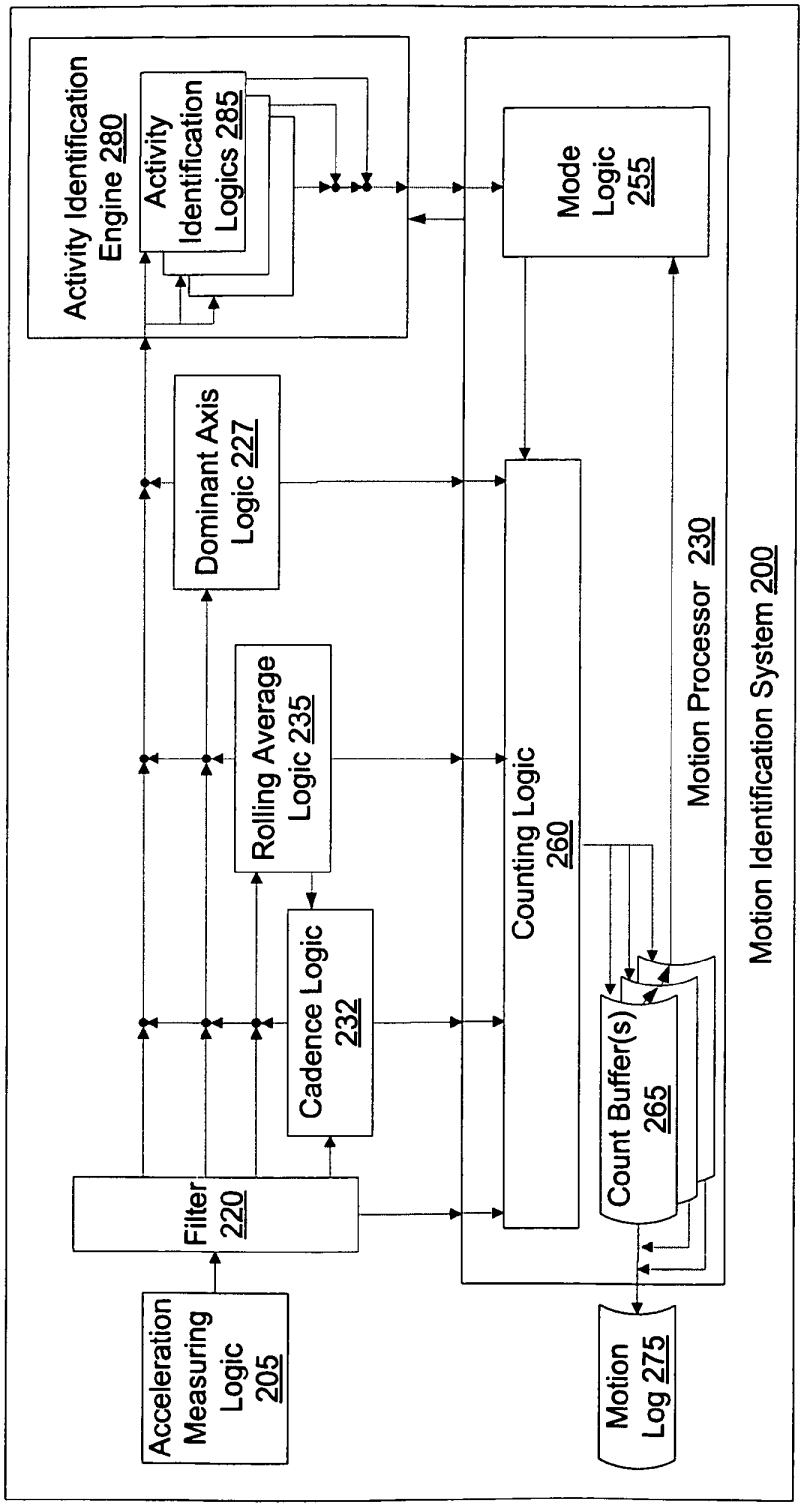
Motion Identification System 200
Activity Identification Engine 280
Activity Identification Logics 285
Mode Logic 255
Dominant Axis Logic 227
Rolling Average Logic 235
Cadence Logic 232
Counting Logic 260
Motion Processor 230
Count Buffer(s) 265
Filter 220
Acceleration Measuring Logic 205
Motion Log 275

Figure 2

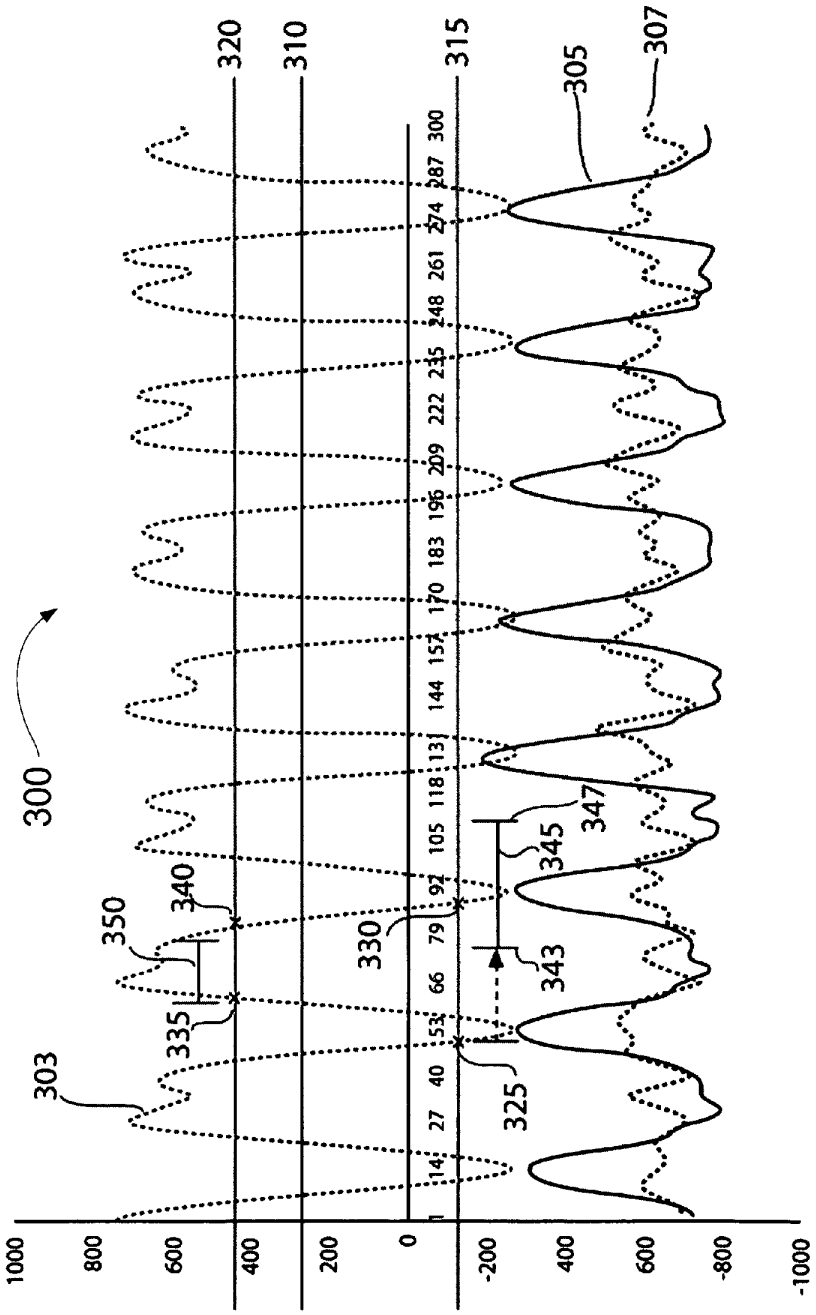
300
303
305
307
310
315
320
325
330
335
340
343
345
347
350
1000
800
600
400
200
0
-200
400
600
-800
-1000
1
14
27
40
53
66
79
92
105
118
131
144
157
170
183
196
209
222
235
248
261
274
287
300

Figure 3A

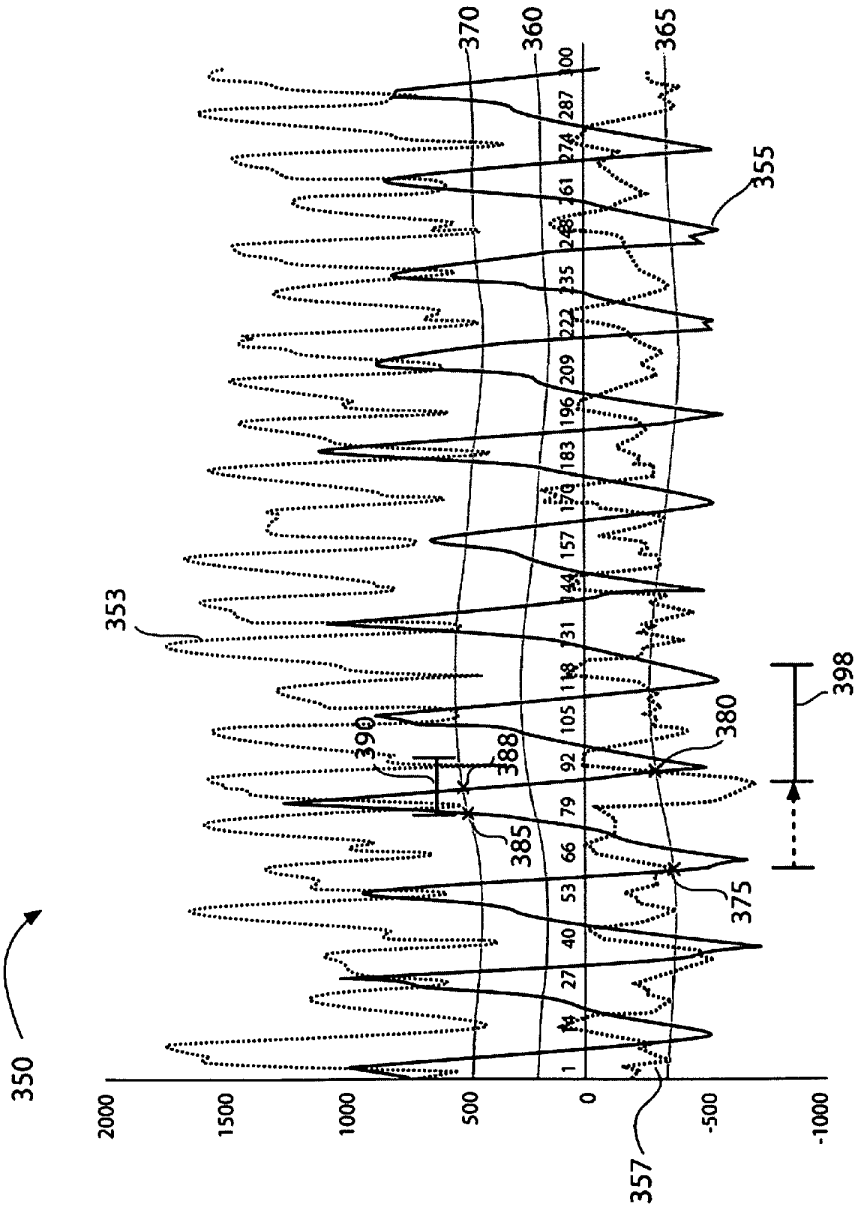
350
353
355
357
360
365
370
375
380
385
388
390
398
2000
1500
1000
500
0
-500
-1000
1
14
27
40
53
66
79
92
105
118
131
144
157
170
183
196
209
222
235
248
261
274
287
300

Figure 3B

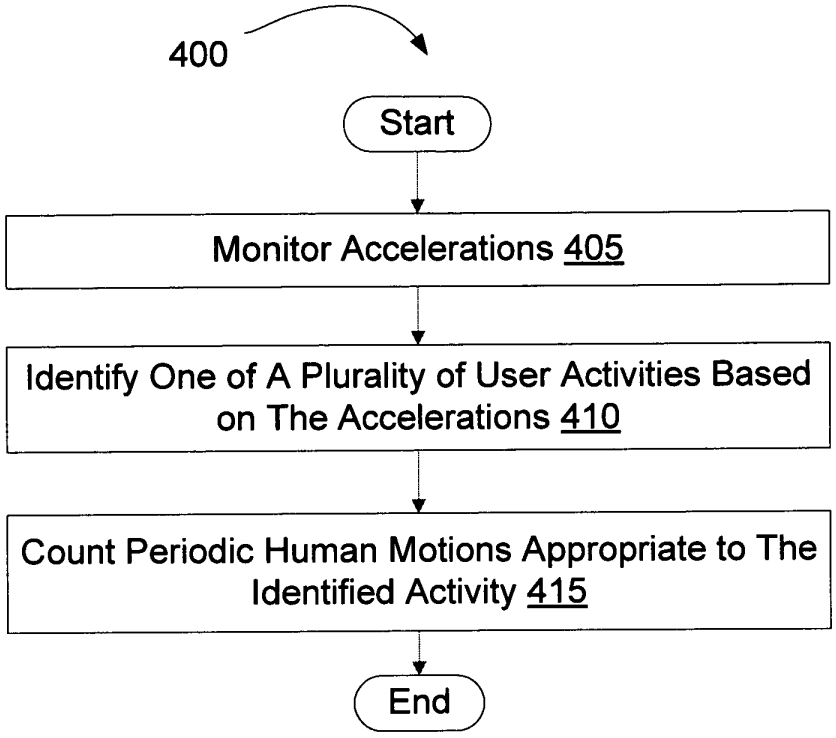
400
Start
Monitor Accelerations 405
Identify One of A Plurality of User Activities Based on The Accelerations 410
Count Periodic Human Motions Appropriate to The Identified Activity 415
End

Figure 4A

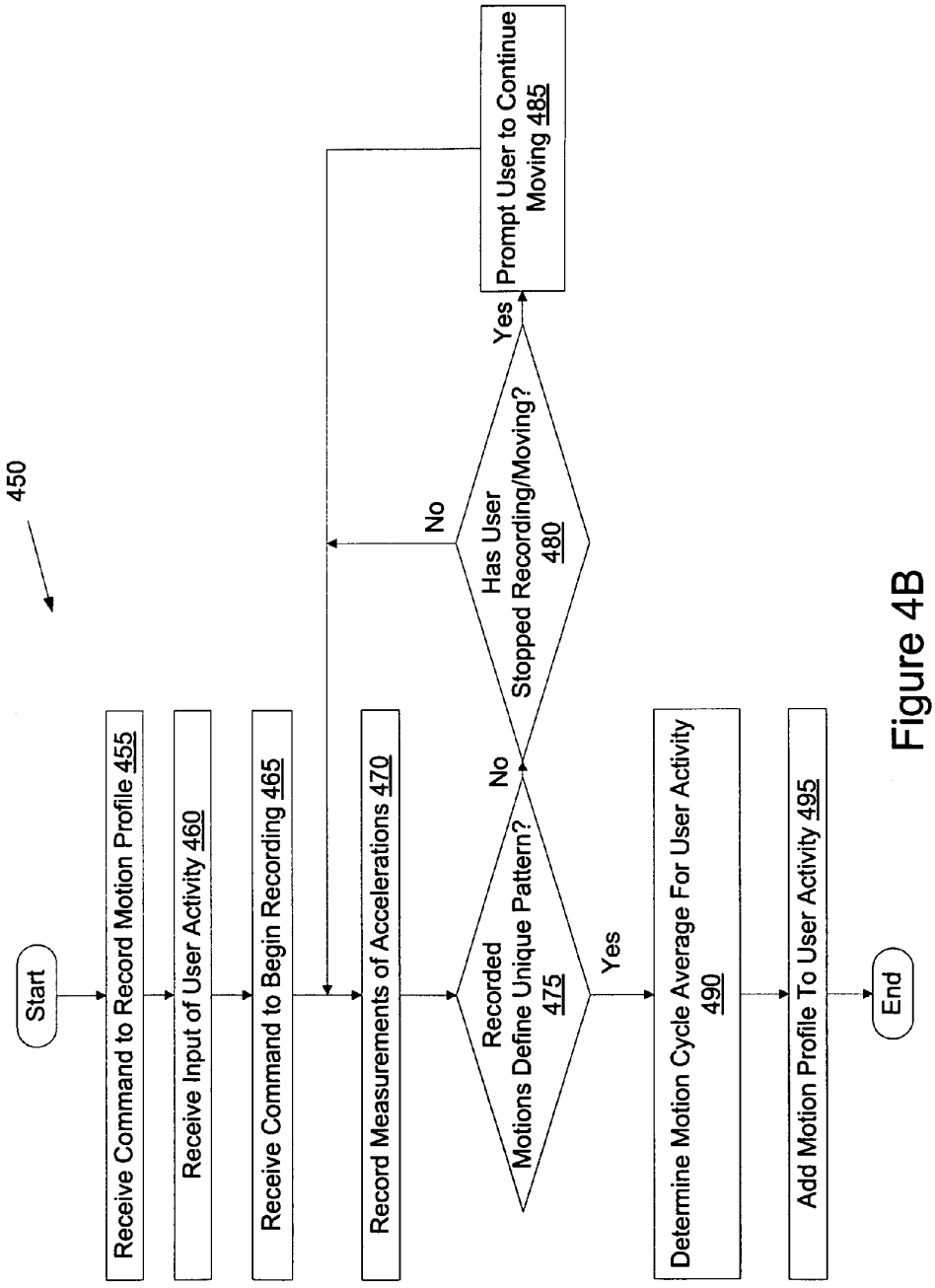
450
Start
Receive Command to Record Motion Profile 455
Receive Input of User Activity 460
Receive Command to Begin Recording 465
Record Measurements of Accelerations 470
Recorded Motions Define Unique Pattern? 475
No
Yes
Has User Stopped Recording/Moving? 480
No
Yes
Prompt User to Continue Moving 485
Determine Motion Cycle Average For User Activity 490
Add Motion Profile To User Activity 495
End

Figure 4B

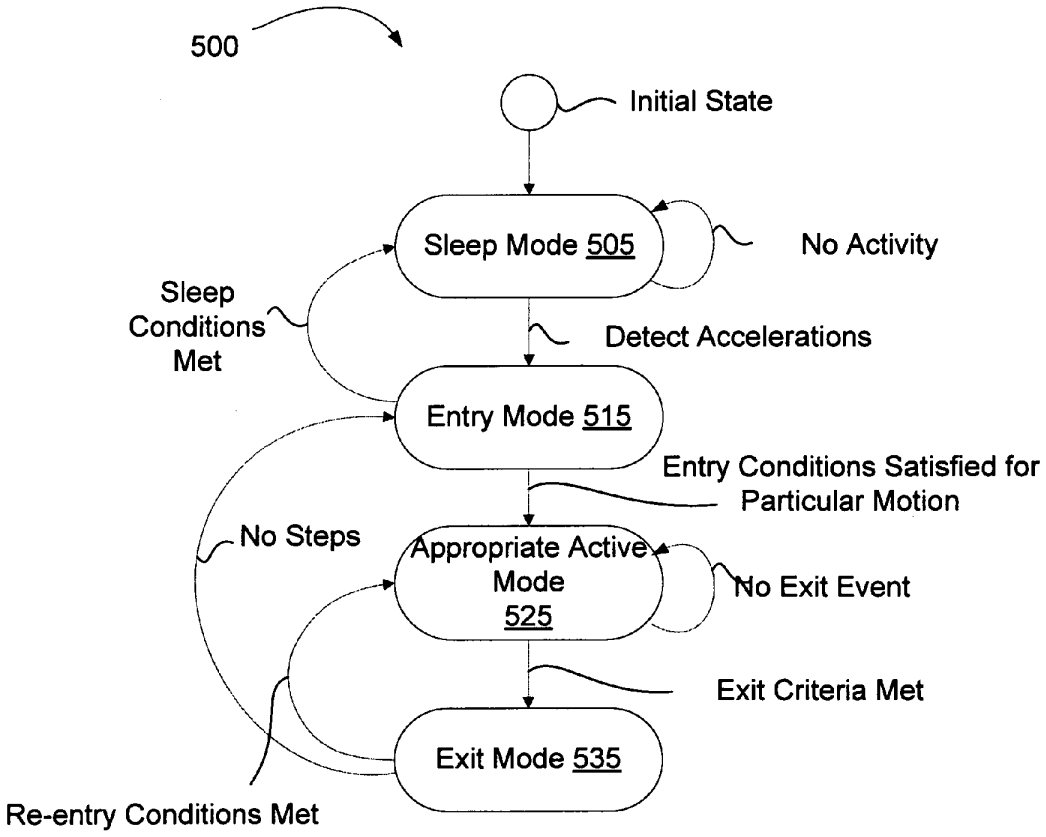
500
Initial State
Sleep Mode 505
No Activity
Sleep Conditions Met
Detect Accelerations
Entry Mode 515
Entry Conditions Satisfied for Particular Motion
No Steps
Appropriate Active Mode 525
No Exit Event
Exit Criteria Met
Exit Mode 535
Re-entry Conditions Met

Figure 5

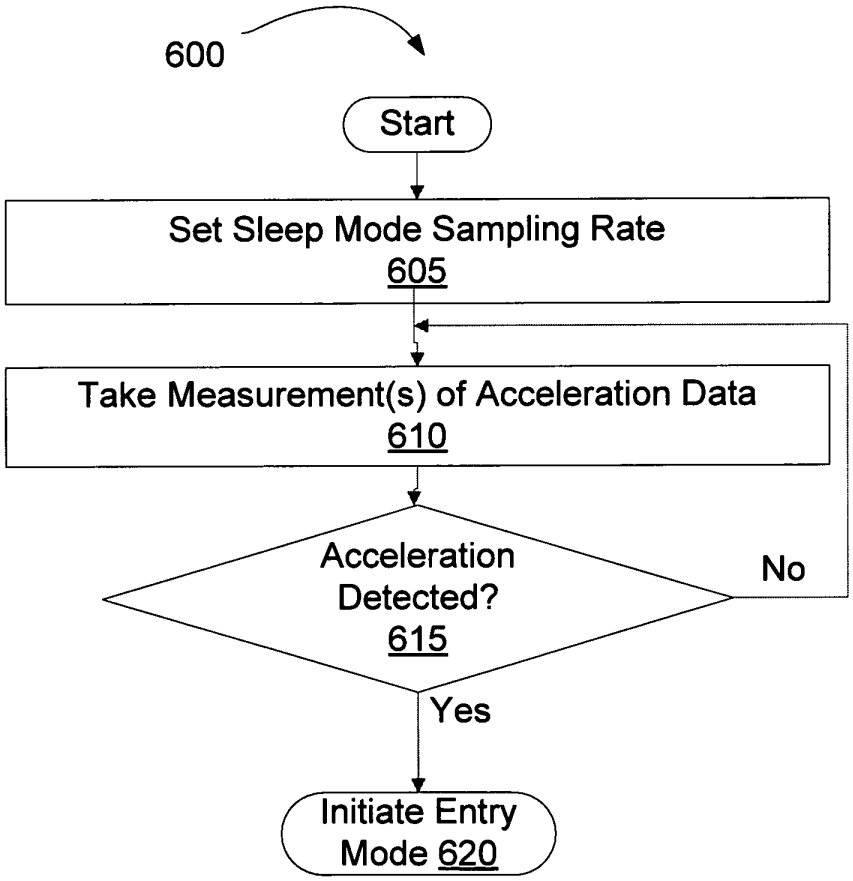
600
Start
Set Sleep Mode Sampling Rate
605
Take Measurement(s) of Acceleration Data
610
Acceleration
Detected?
615
No
Yes
Initiate Entry
Mode 620

Figure 6

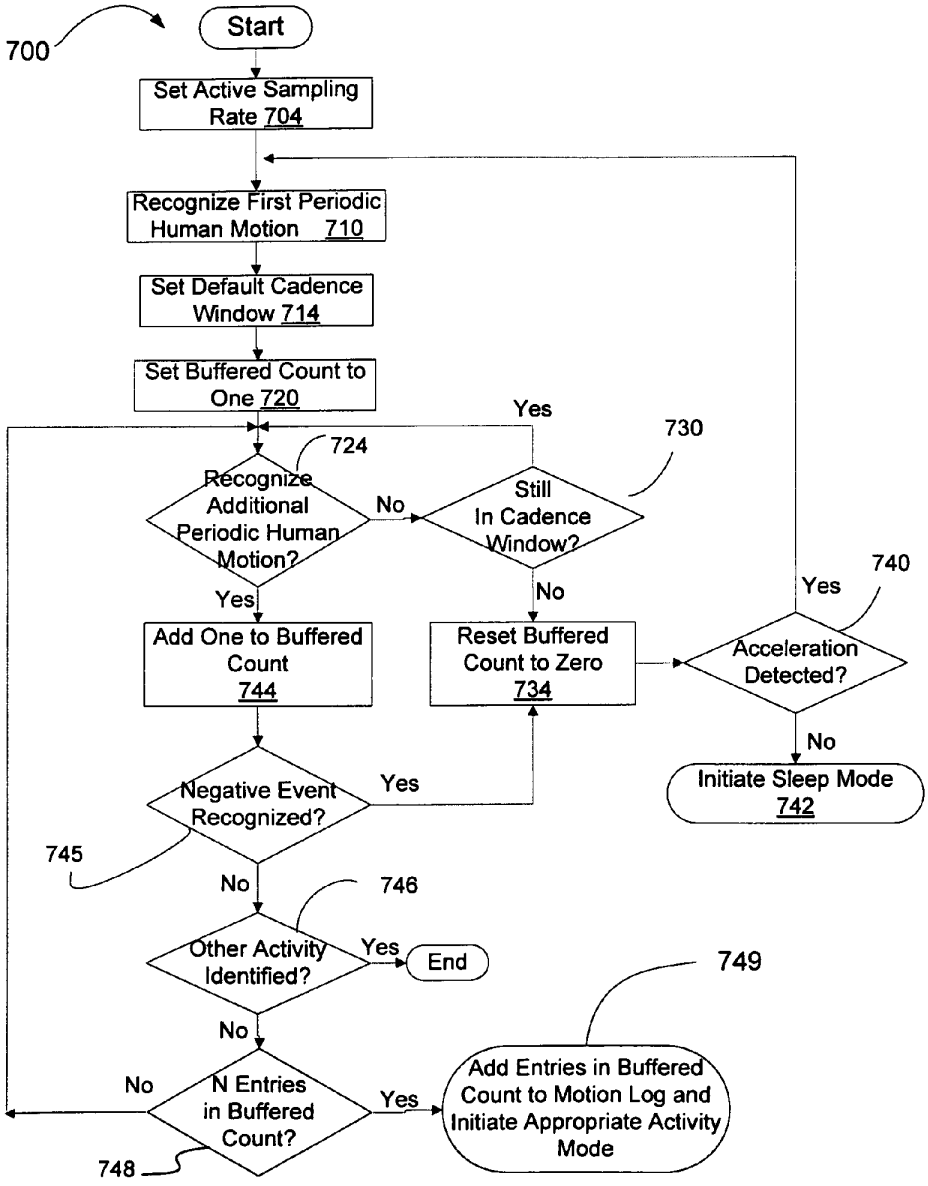
700
Start
Set Active Sampling Rate 704
Recognize First Periodic Human Motion 710
Set Default Cadence Window 714
Set Buffered Count to One 720
724
Recognize Additional Periodic Human Motion?
No
Still In Cadence Window?
730
Yes
No
Yes
Add One to Buffered Count 744
Reset Buffered Count to Zero 734
Acceleration Detected?
740
Yes
No
Initiate Sleep Mode 742
Negative Event Recognized?
Yes
745
No
746
Other Activity Identified?
Yes
End
749
No
No
N Entries in Buffered Count?
Yes
748
Add Entries in Buffered Count to Motion Log and Initiate Appropriate Activity Mode

Figure 7A

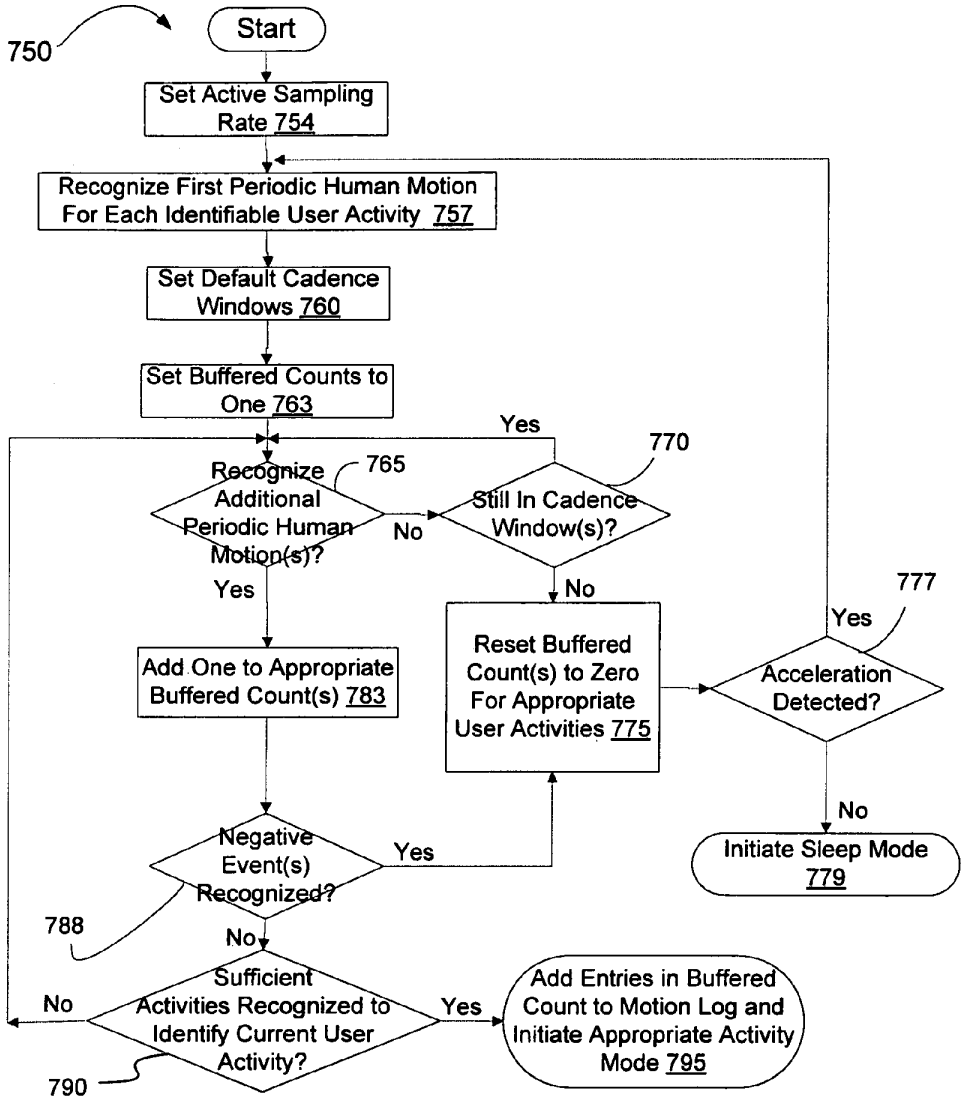
750
Start
Set Active Sampling Rate 754
Recognize First Periodic Human Motion For Each Identifiable User Activity 757
Set Default Cadence Windows 760
Set Buffered Counts to One 763
Yes
765
Recognize Additional Periodic Human Motion(s)?
No
770
Still In Cadence Window(s)?
Yes
No
Add One to Appropriate Buffered Count(s) 783
Reset Buffered Count(s) to Zero For Appropriate User Activities 775
777
Yes
Acceleration Detected?
No
Initiate Sleep Mode 779
Negative Event(s) Recognized?
Yes
788
No
Sufficient Activities Recognized to Identify Current User Activity?
No
Yes
790
Add Entries in Buffered Count to Motion Log and Initiate Appropriate Activity Mode 795

Figure 7B

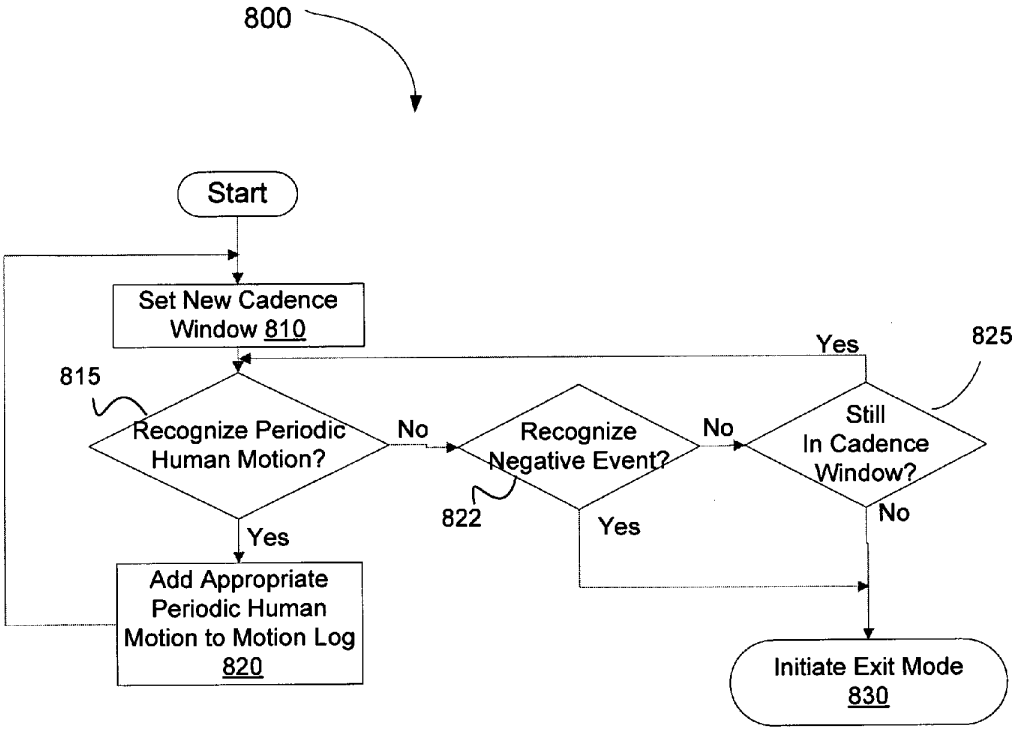
800
Start
Set New Cadence Window 810
815
Recognize Periodic Human Motion?
No
Recognize Negative Event?
822
No
Still In Cadence Window?
825
Yes
Yes
Yes
No
Add Appropriate Periodic Human Motion to Motion Log 820
Initiate Exit Mode 830

Figure 8

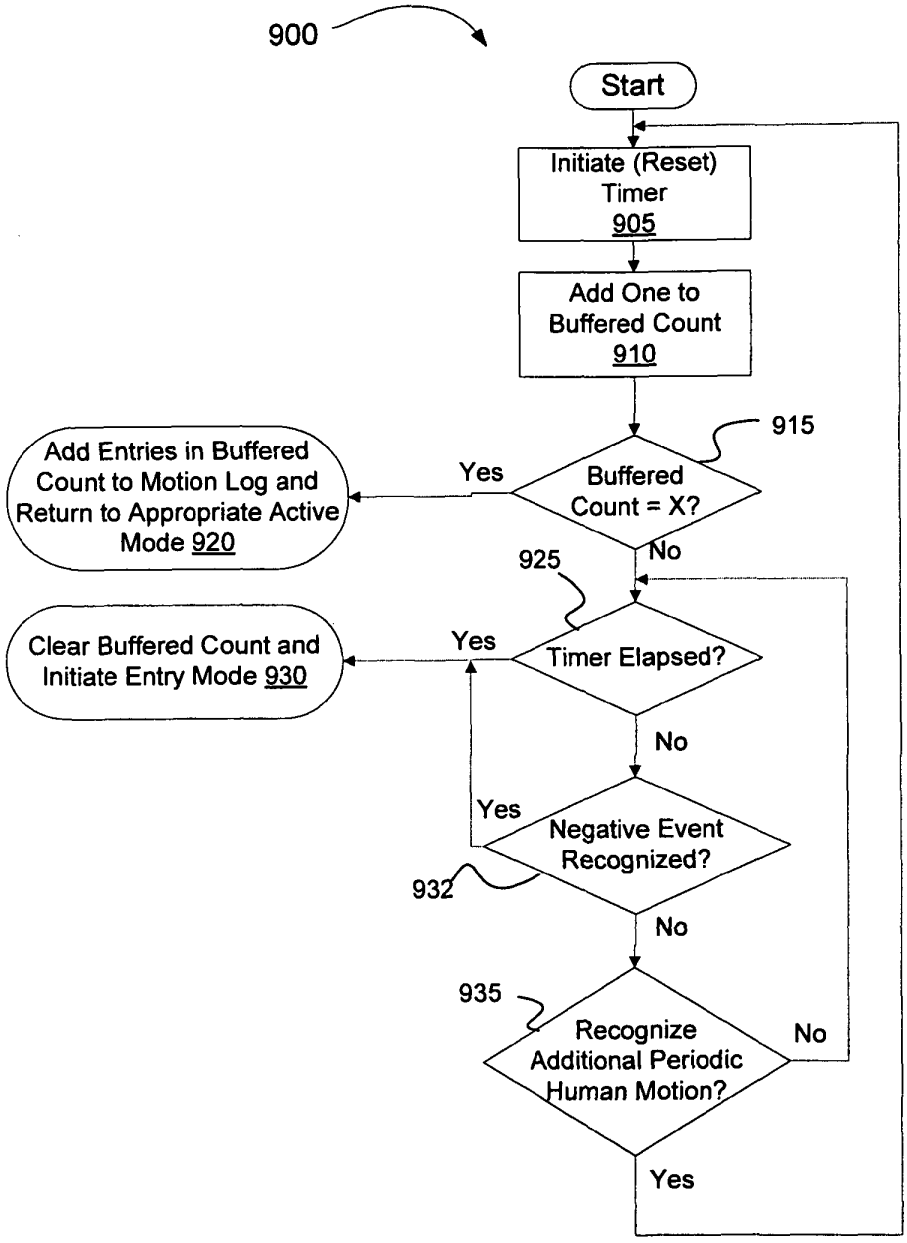
900
Start
Initiate (Reset) Timer 905
Add One to Buffered Count 910
915
Buffered Count = X?
Yes
Add Entries in Buffered Count to Motion Log and Return to Appropriate Active Mode 920
No
925
Timer Elapsed?
Yes
Clear Buffered Count and Initiate Entry Mode 930
No
Negative Event Recognized?
Yes
932
No
935
Recognize Additional Periodic Human Motion?
No
Yes

Figure 9

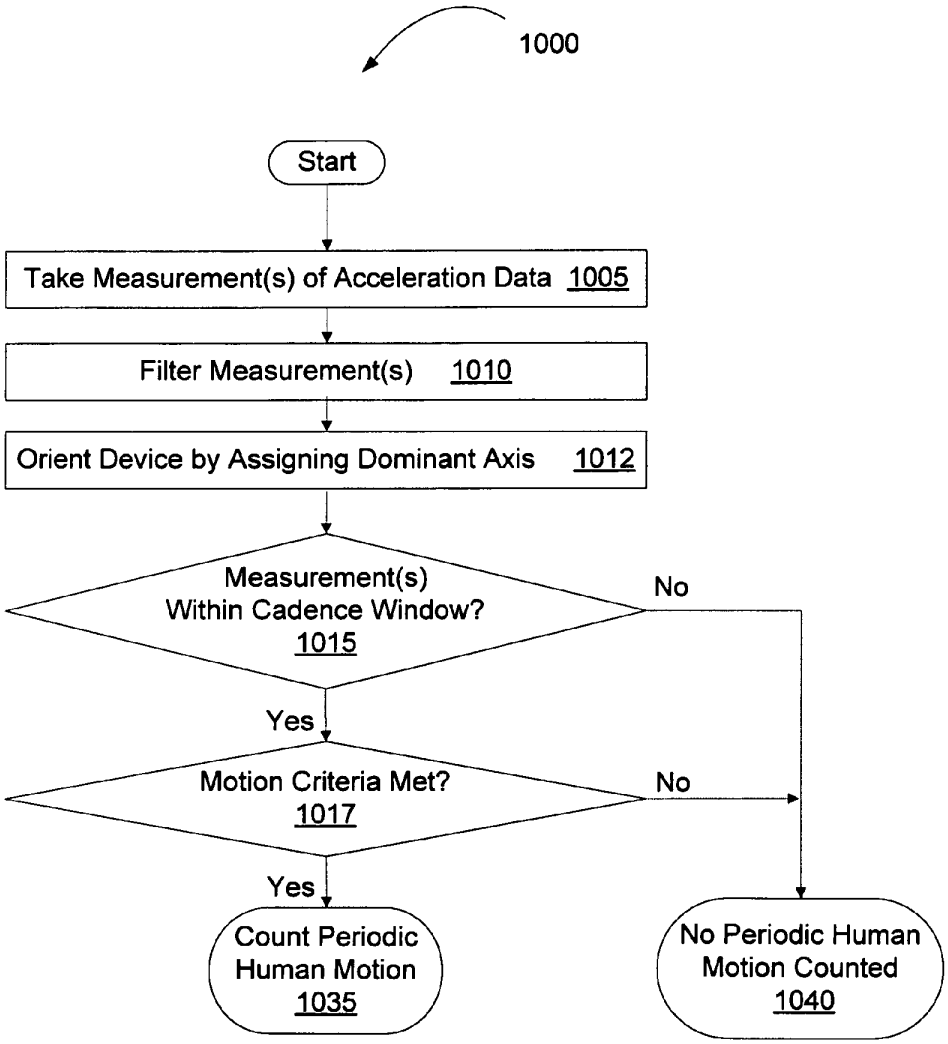
1000
Start
Take Measurement(s) of Acceleration Data 1005
Filter Measurement(s) 1010
Orient Device by Assigning Dominant Axis 1012
Measurement(s) Within Cadence Window? 1015
No
Yes
Motion Criteria Met? 1017
No
Yes
Count Periodic Human Motion 1035
No Periodic Human Motion Counted 1040

Figure 10

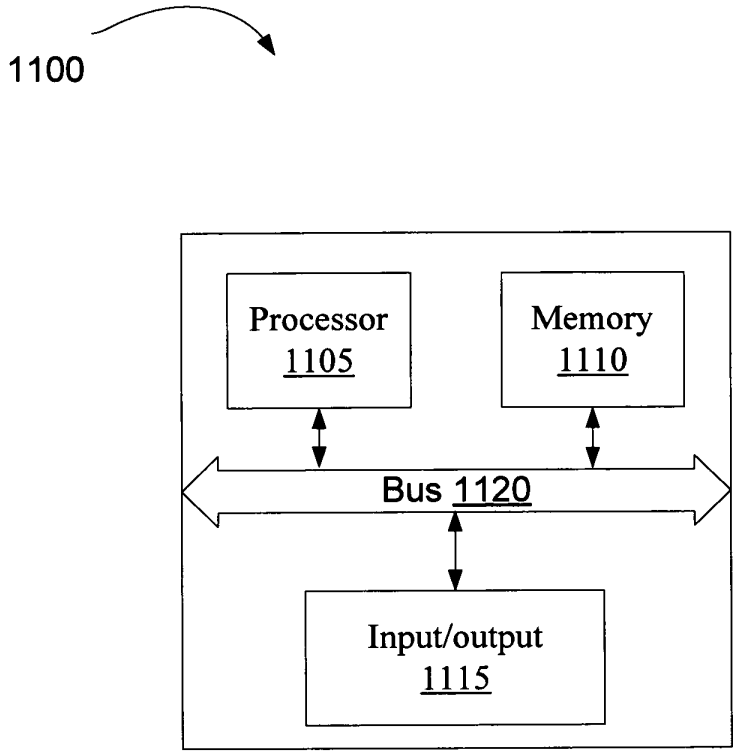

Figure 11

HUMAN ACTIVITY MONITORING DEVICE WITH ACTIVITY IDENTIFICATION

RELATED APPLICATIONS

This patent application claims the benefit under 35 U.S.C. §119(e) of U.S. provisional application No. 60/900,412, filed Feb. 8, 2007, which is herein incorporated by reference.

FIELD OF THE INVENTION

This invention relates to a method of monitoring human activity, and more particularly to identifying user activities and counting periodic human motions appropriate to the identified user activities.

BACKGROUND

The development of Micro-Electro-Mechanical Systems (MEMS) technology has enabled manufacturers to produce inertial sensors (e.g., accelerometers) of sufficiently small size, cost, and power consumption to fit into portable electronic devices. Such inertial sensors can be found in a limited number of commercial electronic devices such as cellular phones, portable music players, pedometers, game controllers, and portable computers.

Step counting devices (e.g., pedometers) are used to monitor an individual's daily activity by keeping track of the number of steps that he or she takes. Steps are counted by sensing accelerations caused by user motion. Step counting devices are not able to detect or count motions other than steps. Nor are step counting devices capable of differentiating between different user activities.

Some step counting devices may be attached to and receive input from external sensors (e.g., a bike cadence sensor) to detect a motion other than a step. However, such step counting devices rely on external sensors for such monitoring capability. These devices are not capable of detecting or counting motions other than steps without the input from external sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example, and not by way of limitation, and can be more fully understood with reference to the following detailed description when considered in connection with the following figures:

FIG. **1** is a block diagram illustrating an electronic device, in accordance with one embodiment of the present invention;

FIG. **2** is a block diagram illustrating a motion identification system, in accordance with one embodiment of the present invention;

FIG. **3**A illustrates a first exemplary motion cycle graph that shows a user engaged in a first user activity;

FIG. **3**B illustrates a second exemplary motion cycle graph **350** that shows a user engaged in a second user activity;

FIG. **4**A illustrates a flow diagram for a method of monitoring human activity using an inertial sensor, in accordance with one embodiment of the present invention;

FIG. **4**B illustrates a flow diagram for a method of recording a motion profile, in accordance with one embodiment of the present invention;

FIG. **5** shows a state diagram for the behavior of a system for monitoring human activity, in accordance with one embodiment of the present invention;

FIG. **6** illustrates a flow diagram for a method of operating an electronic device in sleep mode, in accordance with one embodiment of the present invention;

FIG. **7**A illustrates a flow diagram for a method of operating an electronic device in entry mode, in accordance with one embodiment of the present invention;

FIG. **7**B illustrates a flow diagram for a method of operating an electronic device in entry mode, in accordance with another embodiment of the present invention;

FIG. **8** illustrates a flow diagram for a method of operating an electronic device in an active mode, in accordance with one embodiment of the present invention;

FIG. **9** illustrates a flow diagram for a method of operating an electronic device in an exit mode, in accordance with one embodiment of the present invention;

FIG. **10** illustrates a flow diagram for a method of recognizing a periodic human motion, in accordance with one embodiment of the present invention; and

FIG. **11** illustrates a block diagram of a machine in the exemplary form of a computer system within which a set of instructions may be executed in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Embodiments of the present invention are designed to monitor human activity using an inertial sensor. In one embodiment, accelerations are monitored, and a current user activity is identified from multiple recognizable user activities based on the accelerations. These activities include any activities based on periodic human motions, including, for example: walking, inline skating, bicycling, exercising on an elliptical machine, exercising on a rowing machine, and cross country skiing. Periodic human motions may then be counted that are appropriate to the current user activity. In one embodiment, the system provides user data on each of the activities that were performed. In this way, a user can monitor his or her overall activity level, as well individual activities.

FIG. **1** is a block diagram illustrating an electronic device **100**, in accordance with one embodiment of the present invention. In one embodiment, the electronic device **100** is a portable electronic device that includes one or more inertial sensors. The inertial sensors may measure accelerations along a single axis or multiple axes. The inertial sensors may measure linear as well as rotational (angular) accelerations.

The electronic device **100** may be used to identify user activities and count periodic human motions appropriate to the identified user activities. In one embodiment, electronic device **100** operates in conjunction with a server (not shown) to identify user activities and count periodic human motions. In one embodiment, periodic human motions may be accurately counted regardless of the placement and/or orientation of the device **100** on a user. For example, the electronic device **100** may be carried in a backpack, pocket, purse, hand, or elsewhere, and accurate periodic human motions may still be counted. In one embodiment, the device **100** is placed in one of multiple locations on a human to facilitate accurate detection of periodic human motions. For example, the electronic device **100** may be placed in a pocket while bicycling to ensure the greatest accuracy in counting pedal motions. Periodic human motions may be accurately counted whether the electronic device **100** maintains a fixed orientation or changes orientation during operation.

The electronic device **100** in one embodiment comprises an acceleration measuring logic **105**, an activity identification engine **110**, a motion processor **120**, and a motion log **125**. The acceleration measuring logic **105** may be an inertial

sensor or other acceleration sensitive instrument. The acceleration measuring logic **105** may continuously take measurements of acceleration data. The measurements of acceleration data are taken at a sampling rate that may be fixed or variable. In one embodiment, the acceleration measuring logic **105** receives a timing signal from a timer (not shown) in order to take measurements at the sampling rate. In one embodiment, the acceleration measuring logic **105** is coupled to the activity identification engine **110** and to the motion processor **120**, and acceleration measurement data is sent to the activity identification engine **110** and to the motion processor **120** for processing.

In one embodiment, measurement data is processed by the activity identification engine **110** to identify a user activity. The activity identification engine **110** may identify the user activity from a plurality of identifiable user activities. The activity identification engine **110** may identify a user activity by monitoring for different events, each event indicative of a different type of activity. In one embodiment, when enough events indicative of a particular user activity are detected, the activity identification engine **110** notifies the motion processor **120** that the identified activity is being performed by the user.

The motion processor **120** may process acceleration measurement data to detect periodic human motions. In one embodiment, a series of motion criteria are applied to the acceleration measurement data. If each of the motion criteria are satisfied, a periodic human motion may be identified, and counted. In one embodiment, a different set of motion criteria may apply for each user activity. In one embodiment, criteria may include positive criteria (ones that must be met to classify a motion in a certain way) and negative criteria (ones that cannot be met to classify a motion in a certain way). Once the activity identification engine **110** has identified a user activity, the motion processor **120** may apply the set of motion criteria specific to the identified activity to detect appropriate periodic human motions. When an appropriate periodic human motion is detected, it may be recorded in the motion log **125**.

If no user activity has been identified by the activity identification engine **110**, in one embodiment possible periodic human motions are buffered by the motion processor **120**. Once the activity identification engine **110** identifies the user activity, these buffered possible periodic human motions may be recorded in the motion log **125** as periodic human motions appropriate to the identified user activity.

The motion log **125** may maintain separate data sets for each type of periodic human motion. For example, the motion log **125** may have a first record of the number of steps walked in a day and a second record of the number of strides a user has inline skated in a day. The motion log **125** may also include additional statistics for different periodic human motions, for example the average walking speed, the length of time and time in a day during which a particular activity was performed, etc.

FIG. **2** is a block diagram illustrating a motion identification system **200**, in accordance with one embodiment of the present invention. The motion identification system **200** in one embodiment may include an electronic device. In one embodiment, the electronic device is a portable electronic device that includes one or more inertial sensors. In another embodiment, the motion identification system **200** includes an electronic device coupled to a server. The distribution of the functionality between the portable device and the server may vary. In one embodiment, the motion identification system **200** comprises a filter **220**, a cadence logic **232**, a rolling average logic **235**, a dominant axis logic **227**, an activity identification engine **280**, a motion processor **230** and a motion log **275**.

The acceleration measuring logic **205** may be an inertial sensor or other acceleration sensitive instrument. The acceleration measuring logic **205** may continuously take measurements of acceleration data at a sampling rate that may be fixed or variable. In one embodiment, the acceleration measuring logic **205** receives a timing signal from a timer (not shown) in order to take measurements at the sampling rate. In one embodiment, the acceleration measuring logic **205** is a 3-dimensional accelerometer. In one embodiment, the sampling rate of the acceleration measuring logic **205** may be based on a level of activity detected. In one embodiment, for slower motions, the sampling rate is decreased.

In one embodiment, the acceleration measuring logic **205** is coupled to the filter **220**. Measurement data may be processed by the filter **220** to remove noise. The filter **220** may be implemented in hardware, software, or both hardware and software. In one embodiment, the filter **220** includes multiple filters, and a determination of which filters to apply to the measurement data is made based upon the type of user activity detected. For example, a low pass filter may be used to remove high frequency noise that would interfere with step counting when a user is walking. In contrast, a high pass filter may be used when quick motions are to be monitored.

Many types of motions that are useful to keep track of have a periodic set of movements. Specific periodic human motions may be characteristic of different types of user activity. For example, to walk, an individual must lift a first leg, move it forward, plant it, then repeat the same series of motions with a second leg. In contrast, a person inline skating performs a repeated sequence of pushing, coasting and liftoff for each leg. For a particular individual, the series of walking motions will usually occur in about the same amount of time, and the series of skating motions will usually occur in about the same amount of time. The repeated set of motions can be considered a unit, and defines the motion cycle. The amount of time that it takes to complete one motion cycle defines the motion cycle's period, and the number of motion cycles that occur in a given unit of time define the motion cycle's cadence.

In one embodiment, filtered measurement data may be passed on to the cadence logic **232**. The cadence logic **232** may determine a period and/or cadence of a motion cycle. The period and/or cadence of the motion cycle is generally based upon user activity (e.g. inline skating, biking, running, walking, etc). In one embodiment, the motion cycle's period is updated after each periodic human motion. The current motion cycle period may be a rolling average of the motion cycle periods over the previous set of motions of the same activity type. This rolling average data may be received from the rolling average logic **235**, as discussed in more detail below.

In one embodiment, the cadence logic **232** maintains one or more cadence windows. A cadence window is a window of time since a last periodic human motion was counted that is looked at to detect a new periodic human motion. When motion criteria (e.g., threshold conditions) are met within a cadence window, a periodic human motion is detected, whereas when motion criteria are met outside of the cadence windows no periodic human motion is detected. A cadence window may be used to facilitate accurate measurement of a periodic human motion (e.g., a step, inline skating stride, bicycle pedal, rowing stroke, etc.).

A cadence window may be set based on the period and/or cadence of the actual motion cycle (e.g., a stepping period),

on set limits, and/or on other determiners. In one embodiment, the cadence window is determined by measuring lengths of time since the most recent periodic human motion was counted. In one embodiment, the cadence window is a dynamic cadence window that continuously updates as a user's cadence changes during a particular activity. For example, using a dynamic cadence window, a new cadence window length may be set after each periodic human motion. If no previous periodic human motions have been detected, or if fewer than a set number of periodic human motions to determine a dynamic cadence window have been detected, a default cadence window may be used. Once enough periodic human motions have been detected to determine a dynamic motion cycle cadence or period, the cadence window may be set to the determined motion cycle period plus or minus an error factor. In one embodiment, a count of between about two to about ten periodic human motions is sufficient to set a dynamic cadence window.

In one embodiment, a separate cadence window may be maintained for each identifiable user activity. Each identifiable user activity may have, for example, a unique default cadence window. When no specific current user activity has yet been identified, these separate cadence windows may be maintained concurrently for each of the possible user activities. Periodic human motions that occur outside of a default cadence window may indicate that the associated user activity is currently not being performed.

Once the motion cycle's period is detected, the cadence logic **232** may set one or more sample periods for the rolling average logic **235** to use based upon the motion cycle's period. A sample period can include a specified time frame over which obtained measurements are used to perform a calculation. In one embodiment, the sample period(s) are set such that at least one sample period is approximately the length of, or longer than, the motion cycle's period. In one embodiment, a sample period is set such that it is a multiple of the motion cycle's period.

In one embodiment, the rolling average logic **235** may receive filtered measurement data from the filter **220** and one or more sample periods from the cadence logic **232**. The rolling average logic **235** creates one or more rolling averages of accelerations as measured by the inertial sensor(s) over the sample period(s) set by the cadence logic **232**. The rolling averages of accelerations may be used for determining an orientation of the electronic device, for determining thresholds to compare acceleration measurements against, and/or for other purposes. In one embodiment, the rolling average logic **235** creates one or more rolling averages of accelerations for determining an orientation of the electronic device **200**, at least one rolling average having a period that is at least the motion cycle's period. In one embodiment, the rolling average logic **235** creates a rolling average of accelerations for determining a lower threshold to compare acceleration measurements against, the rolling average having a sample period that is at least twice the stepping period.

The rolling average logic **235** may create one or more rolling averages of data other than accelerations. In one embodiment, the rolling average logic **235** creates a rolling average of motion cycle periods, where the rolling average is the rolling average time between periodic human motions. In one embodiment, the rolling average of motion cycle periods is calculated over the past four counted periodic human motions. The rolling average of the motion cycle periods may be used by the cadence logic **232** to dynamically determine a cadence window and a current motion cycle cadence.

In one embodiment, rolling averages may be maintained in registries that keep track of rolling average values and the number of samples that were used to calculate current rolling average values. When a new measurement is taken, it can be incorporated into the rolling average value, and the registry can than be updated with a new rolling average value. Alternatively, the rolling averages may be maintained by buffering the measurements used to calculate the rolling averages. As the buffers fill, oldest measurement data can be discarded and replaced by new measurement data. The measurements in the buffer can be averaged after each measurement to determine a new rolling average.

In one embodiment, the dominant axis logic **227** receives at least filtered acceleration data from the filter **220**, and rolling averages of accelerations from the rolling average logic **235**. In one embodiment, the dominant axis logic **227** receives only rolling averages of accelerations from the rolling average logic **235**. The dominant axis logic **227** may assign a dominant axis based on the received information.

In one embodiment, the dominant axis logic **227** determines an orientation of the electronic device and/or the inertial sensor(s) within the motion identification system **200**. The orientation may be determined based upon the rolling averages of accelerations created by the rolling average logic **235**. In one embodiment, once the orientation is determined, a dominant axis is assigned based upon the orientation. Determining an orientation of the electronic device may include identifying a gravitational influence. The axis with the largest absolute rolling average may be the axis most influenced by gravity, which may change over time (e.g. as the electronic device is rotated). Therefore, a new dominant axis may be assigned when the orientation of the electronic device and/or the inertial sensor(s) attached to or embedded in the electronic device changes.

In one embodiment, the axis with the largest absolute rolling average over the sample period is assigned as the dominant axis. In one embodiment, the dominant axis does not correspond to one of the actual axes of the inertial sensor(s) in a current orientation, but rather to an axis that is defined as approximately aligned to gravity. In one embodiment, the dominant axis corresponds to a virtual axis that is a component of a virtual coordinate system. In one embodiment, the dominant axis setting logic **240** assigns the dominant axis by performing a true gravity assessment, such as by doing trigonometric calculations on the actual axes based on the gravitational influence. In one embodiment, the dominant axis setting logic **240** assigns the dominant axis by comparing the gravitational influence to a data structure such as a lookup table, associative array, hash table, adjacency matrix, etc.

In one embodiment, the dominant axis is determined based on criteria other than a device orientation in relation to gravity. For example, the dominant axis may be determined based on an axis that has a greatest peak to peak variation within a motion cycle. In one embodiment, multiple dominant axes are assigned, each dominant axis being associated with a different user activity. Each of the dominant axes may be assigned based on criteria specific to an associated user activity. For example, a first dominant axis may be assigned to the user activity of walking based on an axis that is most influenced by gravity, and a second dominant axis may be assigned to the user activity of bicycling based on an axis that has the greatest peak to peak variance.

The activity identification engine **280** may receive as an input filtered acceleration measurement data from the filter **220**. The activity identification engine **280** may also receive a cadence and/or period of a current motion cycle from the cadence logic **232**, a current cadence window from the cadence logic **232**, rolling averages (e.g., of accelerations)

from the rolling average logic **235**, and one or more dominant axes from the dominant axis logic **227**.

In one embodiment, the activity identification engine **280** includes multiple activity identification logics **285**. In one embodiment, each of the activity identification logics **285** is set up to determine whether the current acceleration data defines a particular activity. Alternatively, activity identification logic **285** may be capable of identifying two or more different activities. In one embodiment, the activity identification engine **280** includes only a single activity identification logic **285**, which is used to identify all identifiable user activities. Alternatively, there may be separate activity identification logics **285** for each activity, there may be separate activity identification logics **285** for each activity type, or there may be separate activity identification logics **285** based on some other criteria.

An activity identification logic **285** identifies a specific user activity by monitoring for acceleration data indicative of that type of activity. The acceleration data is analyzed and the activity identification logic **285** may make its determination based on one or more of the received acceleration data, motion cycle cadence, motion cycle period, cadence windows, rolling averages, and dominant axes. In one embodiment, when enough events indicative of a particular user activity are detected by an activity identification logic **285**, the activity identification engine **280** notifies the motion processor **230** that the identified activity is being performed by the user. In one embodiment, each time an activity identification logic **285** detects an event indicative of a particular type of activity, that event is forwarded to the motion processor **230**. The motion processor **230** may then determine whether the user is performing the activity associated with the received event or received events. In one embodiment, the activity identification logics **285** also monitor for negative events that indicate that a user is not, performing a particular user activity. These negative events may also be used by the activity identification engine **280** and/or the motion processor **230** to identify a current user activity.

FIGS. **3**A and **3**B illustrate examples of motion data which may be used by an activity identification logic that identifies bicycling by monitoring for positive and negative bicycling events, in accordance with embodiments of the present invention. FIG. **3**A illustrates a first exemplary motion cycle graph **300** that shows a user engaged in a first user activity as analyzed by an activity identification logic that identifies bicycling, in accordance with one embodiment of the present invention. The exemplary motion-cycle graph **300** shows acceleration data taken with a single tri-axis inertial sensor. The acceleration at a given period of time is represented for a first axis **303**, a second axis **305**, and a third axis **307**.

The bicycling identification logic monitors for positive events and negative events that occur when certain motion criteria are satisfied. In one embodiment, the bicycling identification logic uses a dominant axis that is defined by measuring the axis with the largest peak to peak difference. In the illustrated figure, the first axis **303** is the dominant axis, because it has the greatest peak to peak difference. In one embodiment, the bicycling identification logic only examines acceleration data along the dominant axis.

In one embodiment, the bicycling identification logic uses a rolling average of accelerations **310** for the dominant axis to set a first threshold **315** and a second threshold **320**. The first threshold **315** and second threshold **320** may be set based on offsets from the rolling average of accelerations **310**. Alternatively, the first threshold **315** and second threshold **320** may be set based on a percentage of the peak to peak difference, on a percentage of the average of the peak to peak difference, on a percentage of half of the peak to peak difference, or on other criteria. For example, the first threshold **315** may be set at 25% of the peak to peak difference, and the second threshold **320** may be set at 75% of the peak to peak difference.

A first periodic human motion may be detected when the first threshold **315** is first crossed **325** (moving away from zero). This may trigger a positive bicycling event. A second periodic human motion may be detected when the first threshold **315** is crossed a second time **330** (moving away from zero). In one embodiment, if the first threshold **315** is crossed a second time **330** while within a cadence window **345**, a positive bicycling event may be triggered. If the first threshold **315** is not crossed **330** while within the cadence window **345**, a negative bicycling event may be triggered. The cadence window **345** has a cadence window minimum **343** that opens the cadence window **345** some period of time after the first threshold **315** is first crossed **325**, and a cadence window maximum **347** that closes the cadence window **345** some period of time thereafter. In the illustrated example, the first threshold **315** is crossed within the cadence window **345**, triggering a positive bicycling event.

The second threshold **320** may be used by the bicycling identification logic to determine a peak shape for the acceleration measurements along the first axis **303**. In one embodiment, the bicycling identification logic notes each time the second threshold **320** is crossed. In one embodiment, if the time between when the second threshold **320** is first crossed **335** and second crossed **340** is less than a peak window **350**, then a negative bicycling event may be triggered. If the time between when the second threshold **320** is first crossed **335** and second crossed **340** is greater than or equal to the peak window **350**, then a negative bicycling event may not be triggered. In one embodiment, if the second threshold **320** is crossed within 25-35% or 65-75% of the average of the motion cycle's period, the peak is too steep, and a negative event is triggered. In one embodiment, if the second threshold **320** is crossed within certain percentages of the average of the motion cycle's cadence, a negative event is triggered. In the illustrated example, no negative bicycling events are triggered. Moreover, the illustrated example shows an embodiment in which a sufficient number of positive events are triggered to identify the current user activity as bicycling.

FIG. **3**B illustrates a second exemplary motion cycle graph **350** that shows a user engaged in a second user activity as analyzed by an activity identification logic that identifies bicycling, in accordance with one embodiment of the present invention. The exemplary motion-cycle graph **350** shows acceleration data taken with a single tri-axis inertial sensor. The acceleration at a given period of time is represented for a first axis **353**, a second axis **355**, and a third axis **357**.

The bicycling identification logic monitors for positive events and negative events that occur when certain motion criteria are satisfied. In one embodiment, the bicycling identification logic uses a dominant axis that is defined by measuring the axis with the largest peak to peak difference. In the illustrated figure, the second axis **355** is the dominant axis, because it has the greatest peak to peak difference.

In one embodiment, the bicycling identification logic uses a rolling average of accelerations **360** for the dominant axis to set a first threshold **365** and a second threshold **370**. A first periodic human motion may be detected when the first threshold **365** is first crossed **375** (moving away from zero). This may trigger a positive bicycling event. A second periodic human motion may be detected when the first threshold **365** is crossed a second time **380** (moving away from zero). In one embodiment, if the first threshold **320** is crossed a second time **380** while within a cadence window **398**, a positive

bicycling event may be triggered. If the first threshold **365** is not crossed **380** while within the cadence window **398**, a negative bicycling event may be triggered. In the illustrated example, the first threshold **365** is crossed within the cadence window **398**, triggering a positive bicycling event.

The second threshold **370** may be used by the bicycling identification logic to determine a peak shape for the acceleration measurements along the second axis **355**. In one embodiment, the bicycling identification logic notes each time the second threshold **370** is crossed. The time between when the second threshold **370** is first crossed **385** and second crossed **388** is less than a peak window **390**, triggering a negative bicycling event. The negative bicycling event may reset a counter that counts a number of positive bicycling events. Each illustrated peak would trigger a negative bicycling event. Therefore, not enough positive bicycling events are triggered to identify the current user activity as bicycling.

Returning to FIG. **2**, the motion processor **230** may receive positive and negative events from the activity identification logics **285** of the activity identification engine **280**. The motion processor **230** may also receive dominant axis data from the dominant axis logic **227**, rolling average data from the rolling average logic **235**, a cadence and period for a current motion cycle from the cadence logic **232**, cadence windows from the cadence logic **232**, and filtered acceleration data from the filter **220**. The motion processor **230** may include a counting logic **260**, mode logic **255**, and one or more count buffers **265**.

In one embodiment, the mode logic **255** receives positive and negative events from the activity identification logics **285**. The mode logic **255** may then determine an appropriate mode for the counting logic **260** based on the received events. The mode logic **255** may also determine an appropriate mode based on the count buffers **265**. For example, in one embodiment, while in an entry mode, the first count buffer to reach a predetermined value determines which active mode to initiate. In one embodiment, the mode logic **255** includes a plurality of active modes, each active mode corresponding to a different activity. In one embodiment, the mode logic **255** includes an entry mode, an exit mode and a sleep mode. Operating modes are discussed in greater detail below in reference to FIG. **5**.

The counting logic **260** may receive data from the dominant axis logic **227**, rolling average logic **235**, cadence logic **232** and filter **220**. The counting logic **260** may use this data to count periodic human motions. In one embodiment, the behavior of the counting logic **260** is determined by its current operating mode.

The counting logic **260** may determine which measurements to use to determine if a periodic human motion has occurred. In one embodiment, the counting logic **260** may monitor accelerations relative to the dominant axis, and select only those measurements with specific relations to the dominant axis for measurement. For example, only accelerations that are approximately parallel to the dominant axis may be selected (e.g., in walking active mode), or alternatively, only accelerations that are approximately perpendicular to the dominant axis may be selected (e.g., in rowing active mode). In one embodiment, the counting logic **260** selects only measurements of acceleration data along the dominant axis. In alternative embodiments, measurements of acceleration data along other axes may also be used.

Selected measurements may be compared to motion criteria to determine whether a periodic human motion has occurred, and to determine what type of periodic human motion has occurred. Examples of motion criteria include comparisons of current measurements to previous measurements, comparisons of current measurements to threshold values, slope analysis, curve fitting analysis, peak analysis, etc. In one embodiment, the same criteria that are used to identify events by the activity identification logics are also used to count periodic human motions. Alternatively, different criteria may be used. In one embodiment, the motion criteria used are dependent on a current operating mode of the counting logic **260**.

The count buffers **265** keep track of a probable count of periodic human motions. In one embodiment, the motion processor **230** includes a plurality of count buffers **265**, each associated with a different user activity. Alternatively, a single count buffer may be used to buffer periodic human motions for two or more user activities. In one embodiment, a single count buffer **265** maintains buffers for all user activities.

The exact behavior of the count buffers **265** may depend on the operating mode of the counting logic **260**. For example, in entry mode, a separate count buffer may be maintained for each possible user activity. When the system identifies a periodic human motion that meets the criteria of a particular user activity, the count buffer corresponding to that user activity may be incremented. A detected periodic human motion may meet the criteria for a number of different user activities. Until a current user activity is identified, in one embodiment such motion would be counted by each of the corresponding count buffers **265**.

Depending on the current mode, when one of the count buffers **265** reaches a certain number, that count buffer may be emptied, and the motion log **275** updated by the count from the count buffer. This may also cause the motion logic **255** to place the counting logic **260** in an active mode appropriate to the count buffer that was emptied. The number of periodic human motions that must be counted by the a count buffer before they are moved to the motion log **275** may vary from one to ten or more, depending on the current operating mode. Moreover, count buffers corresponding to different user activities, may have different count requirements.

The motion log **275** keeps track of the total number of periodic human motions that have occurred, and the associated activities. In one embodiment, this data is transmitted to a server or remote database. The output of the motion log **275**, in one embodiment, is made available to the user. In one embodiment, the user can view the various activities, and associated data through a web page.

FIG. **4**A illustrates a flow diagram for a method **400** of monitoring human activity using an inertial sensor, in accordance with one embodiment of the present invention. The method may be performed by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as instructions run on a processing device), or a combination thereof. In one embodiment, method **400** is performed by the electronic device **100** of FIG. **1**. In one embodiment, method **400** is performed by the motion identification system **200** of FIG. **2**.

Referring to FIG. **4**A, method **400** begins with monitoring accelerations (block **405**). Accelerations may be monitored with an inertial sensor, or other acceleration monitoring device. The monitored acceleration may include filtered and processed acceleration data, as described above. At block **410**, the motion is identified as corresponding to one of a plurality of user activities based on the accelerations. At block **415**, periodic human motions are counted appropriate to the identified activity. Examples of identifiable user activities include, walking, running, inline skating, rowing, exercising on an elliptical machine, and bicycling. Other user activities may also be identified.

Periodic human motions corresponding to multiple different predetermined user activities may be identified in embodiments of the present invention. Moreover, in one embodiment, new user activities may be added to the list of recognized periodic human motions. To add such periodic human motions to the predetermined user activities, a user may record a new user activity.

FIG. **4**B illustrates a flow diagram for a method **450** of recording a motion profile, in accordance with one embodiment of the present invention. Method **450** may be used to record new user activities, or to calibrate existing user activities to a particular user. Calibration of existing user activities may improve counting accuracy. The method **450** may be performed by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as instructions run on a processing device), or a combination thereof. Method **450** may be performed by the electronic device **100** of FIG. **1**, and by the motion identification system **200** of FIG. **2**.

Referring to FIG. **4**B, the method **450** begins by receiving a command to record a motion profile (block **455**). At block **460**, input is received that indicates the user activity for which the motion profile will be recorded. In one embodiment, the system may enable the user to select one of a displayed list of existing user activities. In one embodiment, the user may select one of the displayed user activities or may choose to identify a new user activity to be associated with the motion profile. If a motion profile is to be recorded for a new user activity, the user may be prompted to enter a name for the new user activity.

At block **465**, a command is received to begin recording. At block **470**, measurements of accelerations are recorded. The measurements of accelerations are recorded while a user performs the user activity for which a motion profile is to be recorded.

At block **475**, the process determines whether the recorded measurements define a unique pattern. In one embodiment, measurements of accelerations are recorded until a unique pattern can be determined. A unique pattern differentiates the recorded pattern from other motion profiles.

If a unique pattern has not yet been identified, the process determines if the user has stopped the recording and/or motion, at block **480**. In one embodiment, if the user stops recording before such a unique pattern is identified, the system prompts the user to continue recording, at block **485**. The process then returns to block **470** to continue recording motion data. If the user has not stopped the recording, the process continues directly to block **470**. The time to determine a pattern may range from recording a single motion cycle, to recording many motion cycles, which may occur over a single second to minutes. In one embodiment, user input may be received to specify the period of a current motion cycle. For example, a user may push a button, make a certain movement, make a loud noise, etc. each time a new periodic human motion ends (e.g., each time a step is completed). This may reduce the number of motion cycles that need to be recorded in order to determine a pattern from the recorded measurements. Alternatively, the period of the motion cycle is determined without user input. In one embodiment, the system utilizes at least two full motion cycles to identify the pattern.

If at block **475**, a unique pattern has been identified, the process continues to block **490**. In one embodiment, the user is notified that the new activity pattern has been successfully identified. At block **490**, in on embodiment a motion cycle average may be determined for the activity. Once a unique pattern of accelerations is determined for the activity, at block **495**, the motion profile may be added to either an existing user activity or to a new user activity.

The unique pattern of accelerations may also be used to determine (set) positive and/or negative events for the activity. For example, if the unique pattern of accelerations shows a repeated sharp acceleration peak along a dominant axis, a sharp acceleration peak along the dominant axis may be added as a new positive event and/or a gradual peak along the dominant axis may be added as a new negative event. If method **450** was initiated to calibrate an existing user profile, the calibration may include adding new positive and/or negative events to the existing positive and/or negative events. If method **450** was initiated to record a new activity, new positive and/or negative events may be assigned to facilitate future identification of the new activity.

FIG. **5** shows a state diagram for the behavior **500** of a system for monitoring human activity, in accordance with one embodiment of the present invention. The system may have multiple operating modes (states) that are navigated between by processing logic that may comprise hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (such as instructions run on a processing device), or a combination thereof. In one embodiment, behavior **500** is the behavior of the electronic device **100** of FIG. **1**. In one embodiment, behavior **500** is the behavior of the electronic device or inertial sensor(s) within motion identification system **200** of FIG. **2**.

The behavior **500** may include multiple operating modes for monitoring human activity: a sleep mode, an entry mode, one or more active modes, and an exit mode. In alternative embodiments, more or fewer modes may be used. In one embodiment, only two modes are used: active mode and non-active mode. The active mode is entered once periodic human motions are detected, while the non-active mode is used for all other states. In alternative embodiments, multiple inactive modes and/or active modes are used. To navigate between modes, certain conditions must be met. The conditions may include exit conditions for terminating an active mode and entry conditions for initiating inactive modes. Each mode has one or more exit and entry conditions.

Use of different conditions for different operating modes increases the reliability of the device that is monitoring the human activity. For example, once an object (e.g., a person) is moving, they are more likely to remain moving than to stop. Likewise, if a person is not moving, they are more likely not to move than to begin moving. Moreover, if a person is running, he is more likely to continue running than to begin bicycling. These principles can be applied by requiring more stringent conditions to be met for a device to initiate an active mode than to continue the active mode. The different modes may each have rules that reflect what is more likely to happen for subsequent measurements. This may reduce or eliminate the number of uncounted periodic human motions and/or false periodic human motion counts.

Referring to FIG. **5**, operating modes in one embodiment include a sleep mode **505**, an entry mode **515**, an active mode **525**, and an exit mode **535**. In one embodiment, the power level of the system or device is linked to these modes.

The first mode initiated is the sleep mode **505**. When no activity (acceleration) is detected, the system remains in sleep mode **505**. When acceleration is detected, an entry mode **515** is initiated. In one embodiment, in sleep mode **505** the inertial sensor has a slow sample rate, thereby reducing power consumption of the system.

Once in entry mode **515**, in one embodiment the sampling rate of the inertial sensor is increased to ensure that acceleration is monitored to detect periodic human motions. In entry

mode **515**, periodic human motions appropriate to all identifiable user activities may be monitored. Therefore, in one embodiment, the sampling rate is sufficiently high to properly detect the fastest possible activity. When entry conditions are satisfied for a particular user activity, an appropriate active mode **525** is initiated. The sampling rate is then adjusted to be appropriate for the activity being detected, in one embodiment. If no entry conditions for any of the identifiable user activities are detected in a period of time, sleep mode **505** is reinitiated. In one embodiment, sleep mode **505** is only initiated if no motion is detected.

Once in the appropriate active mode **525**, acceleration data is monitored to count periodic human motions according to a predefined set of rules or motion criteria. According to one of these criteria, periodic human motions are expected to occur within a set interval (e.g., within a cadence window). When a periodic human motion is counted within the set interval, then the current active mode **525** is continued. When a periodic human motion is not detected within the set interval, an expected periodic human motion has not occurred, and an exit mode **535** is initiated.

In exit mode **535**, processing logic determines whether re-entry conditions are met. When the re-entry conditions are met, the appropriate active mode **525** is reinitiated. If the re-entry conditions are not met within a certain time frame, the process initiates entry mode **515** again. From entry mode **515**, any appropriate active mode **525** may again be entered into if certain entry conditions are satisfied, or the process may return to sleep mode **505**.

FIG. **6** illustrates a flow diagram for a method **600** of operating an electronic device in sleep mode, in accordance with one embodiment of the present invention. In one embodiment, method **600** corresponds to the sleep mode **505** of FIG. **5**. In one embodiment, the method **600** may begin when no relevant acceleration has been detected for a predetermined time interval, or when no periodic human motions have been detected for a predetermined time interval. In one embodiment, when no acceleration above a threshold value is detected for a set period of time, the sleep function is initiated. In another embodiment, when a motion signature indicative of an activity that does not need to be monitored is detected, the sleep function is initiated. For example, when the motion signature of driving is detected, the sleep function may be initiated. The time period that elapses before the sleep mode is initiated may be a fixed value, or it may be adjusted automatically by processing logic or based on user input (e.g. in response to a user selection of desired battery longevity versus desired performance, or based on the last measured cadence window).

Referring to FIG. **6**, method **600** begins with setting a sleep mode sampling rate (block **605**). In one embodiment, a low sampling rate is set. This reduces power consumption and prolongs battery life. In one embodiment, the sleep mode sampling rate is a fixed value. In alternative embodiments, the sleep mode sampling rate can be modified automatically by processing logic based on certain criteria such as time of day, user behavior patterns, etc., or based on user input.

In one embodiment, a sampling function is periodically executed in sleep mode, wherein the sampling function samples acceleration data at a set sampling rate for a set time period. For example, the sampling function may be executed every ten seconds for the duration of one second, and a sampling rate of fifty measurements per second may be set for that one second of operation. In one embodiment, the sampling function repeats at a relatively slow rate (e.g., once every 10 seconds), and the sampling rate within the sampling function is relatively high (e.g., 50 Hz). The sampling function may be used to detect unwanted motion signatures, or to maintain a device in low power sleep mode, for example, while a user is driving in a car.

In one embodiment, the sleep mode sampling rate is set to zero. The sleep mode sampling rate may be set to zero, for example, when an inertial sensor has 'inertial wakeup' functionality. Inertial wakeup functionality enables processing logic to switch from sleep mode to entry mode when an acceleration exceeding a set threshold is detected. The inertial wakeup may be used to simultaneously exit sleep mode and power-up additional functionality.

At block **610**, measurements of acceleration data are taken. At block **615**, processing logic determines whether or not relevant acceleration is detected. Relevant acceleration includes acceleration that meets certain criteria. In one embodiment, the criteria include a lower threshold and an upper threshold. In alternative embodiments, other criteria may also be used, such as a requirement that acceleration be continuously measured for a preset time period.

When no relevant acceleration is detected, or when the 'inertial wakeup' pin has not triggered (for inertial sensors having 'inertial wakeup functionality'), sleep mode continues, and further measurements of acceleration data are taken at the set sleep mode sampling rate (block **610**). When acceleration is detected, sleep mode is terminated and entry mode is initiated (block **620**). In one embodiment, the acceleration that is detected and its rate of change must meet certain criteria to terminate sleep mode.

FIG. **7**A illustrates a flow diagram for a method **700** of operating an electronic device in entry mode, in accordance with one embodiment of the present invention. In one embodiment, method **700** corresponds to the entry mode **515** of FIG. **5**. The entry mode may be initiated when a user first begins an activity in which periodic human motions may be detected. In one embodiment, the method **700** begins when any relevant acceleration is detected. In one embodiment, entry mode is initiated when a measurement of acceleration that meets certain criteria has been detected. In one embodiment, method **700** is initiated when a sleep mode is terminated. In one embodiment, method **700** is performed concurrently by each of the activity identification logics **285** of FIG. **2** when the motion identification system **200** and/or the counting logic **280** of the electronic device are in entry mode.

Referring to FIG. **7**A, method **700** begins by setting the sampling rate to an active sampling rate (block **704**). The active sampling rate is set to facilitate accurate measurements of periodic human motions, and may be a fixed or a dynamically variable rate. A variable sampling rate may automatically adjust depending on a period of a detected motion cycle's cadence, may be user adjusted, may adjust based on applications being run by processing logic, or by other means. The active sampling rate may be set to anywhere between about 10 and about 200 Hz. In one embodiment, the active sampling rate is set to about 15 to 40 Hz.

At block **710**, a first periodic human motion is recognized. Since no previous periodic human motions have been measured, and there is no cadence window, the first periodic human motion may be recognized at any time. Once a first periodic human motion is recognized, a default cadence window is set (block **714**). The default cadence window may have a minimum and maximum such that periodic human motions will be counted for most or all possible motion cycle cadences. A different default cadence window may be set for each activity. In one embodiment, a separate instance of method **700** is run for each instance of an activity identification logic.

In one embodiment, an initial default value for the cadence window is set wide enough to accommodate all users. In one embodiment, the cadence window is then dynamically adjusted to match the specific user. Processing logic may 'learn' (adapt to) a particular user, and may become more accurate as periodic human motions are counted. Processing logic that has the ability to learn or adapt to different users may create an individualized profile for each user. Multiple profiles may also be created for each user, the different profiles reflecting different user activities. For example, a first profile might be created for a user's running and a second profile may be created for a user's walking. Processing logic may switch between different profiles automatically, or manually based on user input. In one embodiment, processing logic compares a current cadence and/or motion cycle pattern to stored profiles. When a current cadence or motion cycle pattern matches that of a stored profile, that profile may be activated.

At block **720**, a buffered count is set to one. At block **724**, processing logic determines whether an additional periodic human motion is recognized. An additional periodic human motion may be recognized if a particular measurement of acceleration meets all the necessary criteria. Different criteria may be necessary for each of the different user activities. One embodiment of these criteria is discussed below with reference to FIG. **10**.

Returning to FIG. **7**A, if an additional periodic human motion is recognized, method **700** continues to block **744**. If no additional periodic human motions are recognized, then processing logic determines whether the time is still within the cadence window (block **730**). If there is still time within the cadence window, the process returns to block **724**. If the cadence window has closed, then the buffered count is reset to zero (block **734**). The process then continues to block **740**.

At block **740**, processing logic determines whether any relevant acceleration is detected. If no relevant acceleration is detected, then sleep mode is initiated (block **742**). If some relevant acceleration is detected, then processing logic returns to block **710** to await recognition of another periodic human motion. If at block **740** an additional periodic human motion was recognized, the process continues to block **744**.

At block **744**, an additional periodic human motion is added to the buffered count. Processing logic then checks whether any negative events have been recognized (**745**). A negative event is an indicator that the motion does not belong to the activity category being tested. If a negative event is recognized, then the process continues to block **734**, and the buffered count is reset to zero. If a negative event is not recognized, then the process continues to block **746**.

At block **746** the process determines whether another user activity associated with a different instance of method **700** has been identified. If another user activity has been identified, then the process ends. If no other user activity has been identified yet, then the process continues to block **748**.

At block **748**, processing logic checks whether there are N periodic human motions in the buffered count. When there are not yet N periodic human motions in the buffered count, the process returns to block **724** to continue in entry mode. When the number of periodic human motions in the buffered count reaches N, the buffered periodic human motions are added to a motion log, and an appropriate active mode is entered into (block **749**).

FIG. **7**B illustrates a flow diagram for a method **750** of operating an electronic device in entry mode, in accordance with another embodiment of the present invention. In one embodiment, method **750** corresponds to the entry mode **515** of FIG. **5**. The entry mode may be initiated when a user first begins an activity in which periodic human motions may be detected. In one embodiment, the method **750** begins when any relevant acceleration is detected. In one embodiment, entry mode is initiated when a measurement of acceleration that meets certain criteria has been detected. In one embodiment, method **750** is initiated when a sleep mode is terminated.

Referring to FIG. **7**B, method **750** begins by setting the sampling rate to an active sampling rate (block **754**). The sampling rate, in one embodiment, depends on the highest sampling rate required by a potentially recognizable activity.

At block **757**, a first periodic human motion is recognized for each identifiable user activity. Since no previous periodic human motions have been measured, and there is no cadence window, the first periodic human motion may be recognized at any time. Once a first periodic human motion is recognized, default cadence windows are set (block **760**). Default cadence windows may be set for each type of identifiable user activity.

At block **763**, a buffered count is set to one for each of the identifiable user activities. At block **765**, processing logic determines whether additional periodic human motions are recognized for each of the identifiable user activities. Different criteria may be used to separately determine whether an additional periodic human motion is recognized for each of the user activities.

For user activities for which an additional periodic human motion is recognized, method **750** continues to block **783**. Concurrently, for user activities for which no additional periodic human motion is recognized, the process continues to block **770**. At block **770**, the process determines whether the time is still within the appropriate cadence window for each appropriate user activity. If there is still time within the appropriate cadence window, the process returns to block **765** for that user activity. If the cadence window has closed, then the appropriate buffered count is reset to zero (block **775**). The process then continues to block **777**.

At block **777**, processing logic determines whether any relevant acceleration is detected. If no relevant acceleration is detected for any of the user activities, then sleep mode is initiated (block **779**). If some relevant acceleration is detected for any user activity, then processing logic returns to block **757** to await recognition of another first periodic human motion for the appropriate user activity.

If at block **765** an additional periodic human motion was recognized, the process continues to block **783** for the appropriate user activity, and an appropriate periodic human motion is added to an appropriate buffer count.

At block **788**, processing logic checks whether any negative events have been recognized for each appropriate user activity. For user activities for which a negative event is recognized, the process continues to block **775**, and the appropriate buffered count is reset to zero. For user activities for which no negative event is recognized, the process continues to block **790**.

At block **790** the process determines whether sufficient periodic human motions have been recognized to identify a current user activity. If sufficient periodic human motions have been recognized for a particular user activity, the process continues to block **795**. At block **795**, the entries in the appropriate buffered count are added to the motion log, and an active mode is initiated for the identified activity.

FIG. **8** illustrates a flow diagram for a method **800** of operating an electronic device in an active mode, in accordance with one embodiment of the invention. In one embodiment, method **800** corresponds to the appropriate active mode **525** of FIG. **5**. The active mode may be initiated when a particular user activity has been identified. In one embodi-

ment, method **800** is initiated when an entry mode is terminated, and/or when an exit mode is terminated.

Referring to FIG. **8**, method **800** begins by setting a cadence window (block **810**). The cadence window may be set based on previous measurement data. In one embodiment, the cadence window is set based on a rolling average of motion cycle periods. In one embodiment, the cadence window may be identical to an appropriate cadence window used during entry mode. Once the cadence window is set, measurement data is checked to determine whether an additional periodic human motion is recognized (block **815**). If an additional periodic human motion is recognized, then it is added to the motion log (block **820**). If no additional periodic human motion is recognized, then the process determines whether a negative event has been recognized **822**. If a negative event has been recognized, the process continues to block **830**, and exit mode is initiated. If no negative event has been recognized, the process continues to block **825**.

At block **825**, the process determines whether the current measurement was taken within the cadence window. If the cadence window has not elapsed, the process returns to block **815**. If the cadence window has elapsed, then an expected periodic human motion was not counted, and an exit mode is initiated (block **830**).

FIG. **9** illustrates a flow diagram for a method **900** of operating an electronic device in exit mode, in accordance with one embodiment of the present invention. In one embodiment, method **900** corresponds to the exit mode **535** of FIG. **5**. The exit mode may be entered into when an expected periodic human motion is not identified in an active mode.

In one embodiment, the requirement(s) for changing from exit mode to an active mode are less strict than the requirement(s) for switching from entry mode to an active mode. Processing logic may assume that when a user has recently performed a periodic human motion, the user is most likely repeat the same periodic human motion. For example, a user who is inline skating is much more likely to continue skating movements than to break into a jog. Processing logic may also assume that if a user is currently inactive, it is most likely that the user will remain inactive. These assumptions may be implemented by imposing more stringent requirements to switch from entry mode to an active mode than to change from exit mode to an active mode. The requirements to remain in an active mode may be even less stringent than the requirements to initiate the active mode, whether from the entry mode or from the exit mode.

An expected periodic human motion may not be identified, for example, when a user stops moving, when extraneous movements such as gestures are made that interfere with the periodic human motion count, or when a device orientation is changed as a periodic human motion occurs. In one embodiment, the exit mode assumes that a periodic human motion has been missed, so that if the exit mode determines that a user is still continuing the same activity, the originally uncounted periodic human motion is not missed.

The process begins by initiating a timer (block **905**). The timer measures the amount of time that has passed since a periodic human motion has been identified. In one embodiment, the timer is a countdown timer that terminates exit mode when the timer reaches zero. In one embodiment, the timer starts counting when a cadence window minimum is reached, and stops counting when a cadence window maximum is reached. In an alternative embodiment, the timer starts counting as soon as the exit mode is initiated, and stops counting when a cadence window maximum is reached.

At block **910**, a periodic human motion is added to a buffered count. At block **915**, processing logic determines whether the buffered count is equal to X, where X is the number of identified periodic human motions that, when reached, return processing logic to an appropriate active mode. In one embodiment, X is between 3 and 8. In one embodiment, the value of X is dependent upon the specific active mode that exit mode was initiated from. If the buffered count is equal to X, then the buffered periodic human motions are added to motion log and the previous (appropriate) active mode is reinitiated (block **920**). If the buffered count is not equal to X, then processing logic proceeds to block **925**.

At block **925**, processing logic determines whether the timer has timed out (allotted time has elapsed). In one embodiment, the timer times out when no periodic human motions are counted within a cadence window. In one embodiment, the timer times out when no periodic human motions are counted in two or more cadence windows. If the allotted time has elapsed, then the buffered count is cleared, and entry mode is initiated (block **930**). If the allotted time has not elapsed, then processing logic determines whether a negative event has occurred (block **932**). If a negative event has occurred, the method returns to block **930**. If no negative event has occurred, the method proceeds to block **935**.

At block **935**, processing logic determines whether an additional periodic human motion is recognized. If an additional periodic human motion is recognized, then the timer is reset (block **905**), the buffered count is incremented by one (block **910**), and on the process continues to block **915**. If a periodic human motion is not recognized, then processing logic returns to block **925** to determine whether the timer has elapsed.

FIG. **10** illustrates a flow diagram for a method **1000** of recognizing a periodic human motion, in accordance with one embodiment of the present invention. In one embodiment, method **1000** may be executed by blocks **710** and **724** of FIG. **7**A, blocks **757** and **765** of FIG. **7**B, block **815** of FIG. **8** and block **935** of FIG. **9**. In one embodiment, method **1000** is performed by electronic device **100** of FIG. **1**, or the motion identification system **200** of FIG. **2**.

Referring to FIG. **10**, the process begins with measurements of acceleration data being taken (block **1005**). Measurements are taken according to a sampling rate, which may vary. In one embodiment, the sampling rate may range from one measurement per second to many measurements a second, depending on the operating mode being used.

At processing block **1010**, in one embodiment measurements are filtered. Measurements can be filtered to remove high frequency data and/or low frequency data. In one embodiment, what data to filter depends on the type of user activity being detected. At processing block **1012**, in one embodiment the inertial sensor is oriented by assigning a dominant axis. Assigning a dominant axis may include calculating rolling averages of acceleration and assigning the dominant axis based on the rolling averages of acceleration. Assigning the dominant axis may also include determining which axis has the largest peak to peak difference.

At block **1015**, processing logic determines whether a measurement is within a cadence window. If the measurement is not within a cadence window, then no periodic human motion may be recognized or counted for that measurement (block **1040**). If the measurement is within the cadence window, the process continues to block **1017**.

At block **1017**, processing logic determines whether motion criteria are met. For example, in one embodiment the process may determine whether acceleration along the dominant axis is greater than a lower threshold. In one embodiment, the process may determine whether the measurement exceeds the rolling average by a set margin. In one embodi-

ment, processing logic may determine whether acceleration along the dominant axis is greater than previous measurements. Other criteria than those mentioned herein may also be used.

If all required motion criteria are met, then the appropriate periodic human motions are counted (block **1035**).

FIG. **11** illustrates a block diagram of a machine in the exemplary form of a computer system **1100** within which a set of instructions, for causing the machine to perform any one or more of the methodologies discussed herein, may be executed. The exemplary computer system **1100** includes a processing device (processor) **1105**, a memory **1110** (e.g., read-only memory (ROM), a storage device, a static memory, etc.), and an input/output **1115**, which communicate with each other via a bus **1120**. Embodiments of the present invention may be performed by the computer system **1100**, and/or by additional hardware components (not shown), or may be embodied in machine-executable instructions, which may be used to cause processor **1105**, when programmed with the instructions, to perform the method described above. Alternatively, the method may be performed by a combination of hardware and software.

Processor **1105** represents one or more general-purpose processing devices such as a microprocessor, central processing unit, or the like. More particularly, the processor **1105** may be a complex instruction set computing (CISC) microprocessor, reduced instruction set computing (RISC) microprocessor, very long instruction word (VLIW) microprocessor, or a processor implementing other instruction sets or processors implementing a combination of instruction sets. The processor **1105** may also be one or more special-purpose processing devices such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), network processor, or the like.

The present invention may be provided as a computer program product, or software, that may be stored in memory **1110**. Memory **1110** may include a machine-readable medium having stored thereon instructions, which may be used to program exemplary computer system **1100** (or other electronic devices) to perform a process according to the present invention. Other machine-readable mediums which may have instruction stored thereon to program exemplary computer system **1100** (or other electronic devices) include, but are not limited to, floppy diskettes, optical disks, CD-ROMs, and magneto-optical disks, ROMs, RAMs, EPROMs, EEPROMs, magnetic or optical cards, flash memory, or other type of media or machine-readable mediums suitable for storing electronic instructions.

Input/output **1115** may provide communication with additional devices and/or components. In one embodiment, input/output **1115** may transmit data to and receive data from, for example, networked computers, servers, mobile devices, etc.

In the foregoing description, numerous specific details have been set forth such as examples of specific systems, languages, components, etc. in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that these specific details need not be employed to practice the present invention. In other instances, well known materials or methods have not been described in detail in order to avoid unnecessarily obscuring the present invention. The invention has been described with reference to specific exemplary embodiments. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A method of monitoring human activity using an inertial sensor, comprising:

monitoring accelerations by a portable electronic device that includes the inertial sensor;

identifying a current user activity from a plurality of potential user activities based on the accelerations, wherein each of the plurality of potential user activities is associated with one of a plurality of types of periodic human motions that are detectable by the portable electronic device, the identifying comprising:

comparing the accelerations to a plurality of motion criteria sets, each of the motion criteria sets being associated with a particular user activity;

incrementing a plurality of buffers, each of the buffers associated with one of the plurality of potential user activities, when the motion criteria associated with the buffer are satisfied, wherein each buffer stores a periodic motion count for an associated user activity, such that a single periodic movement increments a plurality of buffers;

and identifying the potential user activity whose buffer has reached a threshold value as the current user activity;

resetting the buffers associated with activities other than the current user activity, such that the periodic human motions are only counted in one buffer associated with the current user activity;

counting the periodic human motions associated with the current user activity.

2. The method of claim **1**, wherein the plurality of user activities comprise one or more of the following: walking, inline skating, bicycling, exercising on an elliptical machine, exercising on a rowing machine, and cross country skiing.

3. The method of claim **1**, wherein monitoring accelerations comprises monitoring accelerations relative to a dominant axis.

4. The method of claim **3**, further comprising:

continuously determining an orientation of the inertial sensor;

assigning the dominant axis; and

updating the dominant axis as the orientation of the inertial sensor changes.

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

maintaining separate data for each of the plurality of user activities.

6. The method of claim **1**, wherein at least one of the motion criteria sets include a positive criterion that must be met to identify the associated user activity and a negative criterion that must not be met to identify the associated user activity.

7. The method of claim **6**, wherein the at least one of the motion criteria sets further includes a cadence window within which the positive criterion must be met and the negative criterion must not be met to identify the associated user activity, the method further comprising:

for each user activity, resetting the associated buffer when the negative criterion is met within the cadence window.

8. The method of claim **1**, wherein a single set of accelerations cause multiple buffers associated with different user activities to be incremented.

9. The method of claim **1**, further comprising:

using one or more default cadence windows to count periodic human motions prior to identifying the current user activity; and

setting a new cadence window once the current user activity is identified.

10. The method of claim **1**, wherein the current user activity is identified regardless of placement or orientation of the portable electronic device on a user.

11. An inertial sensor based device, comprising:

an activity identification engine to identify a current user activity from among a plurality of identifiable user activities based on motion data, wherein each of the plurality of identifiable user activities is associated with one of a plurality of types of periodic human motions that are detectable by a motion processor, and wherein the identification of the current user activity is made based on detecting two or more instances of the periodic human motion associated with the user activity, the activity identification engine comprising:

a plurality of buffers, each of the plurality of buffers associated with one identifiable user activity, each buffer to store a periodic motion count for the associated identifiable user activity;

a plurality of activity identification logics, wherein each of the plurality of activity identification logics is associated with one of the plurality of buffers, and each of the activity identification logics includes an associated motion criteria set, and each of the plurality of activity identification logics to compare

the motion data to the associated motion criteria set and increment the associated buffer when the criteria for the periodic motion identifiable user activity in the associated motion criteria set are satisfied, such that a single periodic movement increments a plurality of buffers;

the activity identification engine to identify the identifiable activity whose associated buffer has reached a predetermined count as the current user activity, and the activity identification engine to reset the buffers associated with activities other than the current user activity; and the motion processor, coupled to the activity identification engine, the motion processor to count the periodic human motions associated with the current user activity.

12. The device of claim **11**, wherein the plurality of user activities comprise one or more of the following: walking, inline skating, bicycling, exercising on an elliptical machine, exercising on a rowing machine and cross country skiing.

13. The device of claim **11**, further comprising:

a dominant axis logic, to continuously determine an orientation of the device, to assign a dominant axis, and to update the dominant axis as the orientation of the device changes; and

the motion processor further configured to count the periodic human motions by monitoring accelerations relative to the dominant axis.

14. The device of claim **11**, further comprising:

a motion log to maintain separate data for each of the plurality of periodic human motions.

15. The inertial sensor based device of claim **11**, wherein each of the motion criteria sets includes a positive criterion that must be met to identify the associated user activity and a negative criterion that must not be met to identify the associated user activity.

16. The inertial sensor based device of claim **15**, wherein each of the motion criteria sets further includes a cadence window within which the positive criterion must be met and the negative criterion must not be met to identify the associated user activity, and wherein each of the plurality of activity identification logics to reset the associated counter when the negative criterion is met within the cadence window.

17. A non-transitory computer readable storage medium including instructions that, when executed by a processing system, cause the processing system to perform a method comprising:

monitoring accelerations by an inertial sensor based device; identifying a current user activity from a plurality of potential user activities based on the accelerations, wherein each of the plurality of potential user activities is associated with one of a plurality of types of periodic human motions that are detectable by the inertial sensor based device, the identifying comprising:

comparing the accelerations to a plurality of motion criteria sets, each of the motion criteria sets having an associated potential user activity;

for each potential user activity, incrementing a buffer associated with the potential user activity when the associated motion criteria for the periodic motion are satisfied, wherein the buffer is one of a plurality of buffers storing a periodic motion count for an associated user activity, such that a single periodic movement increments a plurality of buffers;

and identifying the potential user activity whose associated buffer has reached a threshold value as the current user activity;

resetting buffers associated with activities other than the current user activity; and

counting the periodic human motions associated with the current user activity.

18. The non-transitory computer readable storage medium of claim **17**, wherein the plurality of user activities comprise one or more of the following: walking, inline skating, bicycling, exercising on an elliptical machine, rowing, and cross country skiing.

19. The non-transitory computer readable storage medium of claim **17**, wherein monitoring accelerations comprises monitoring accelerations relative to a dominant axis.

20. The non-transitory computer readable storage medium of claim **19**, the method further comprising:

continuously determining an orientation of the inertial sensor;

assigning the dominant axis; and

updating the dominant axis as the orientation of the inertial sensor changes.

21. The non-transitory computer readable storage medium of claim **17**, the method further comprising:

maintaining separate data for each of the plurality of user activities.

22. The non-transitory computer readable storage medium of claim **17**, wherein each of the motion criteria sets includes a positive criterion that must be met to identify the associated user activity, a negative criterion that must not be met to identify the associated user activity.

23. The non-transitory computer readable storage medium of claim **22**, wherein each of the motion criteria sets further includes a cadence window within which the positive criterion must be met and the negative criterion must not be met to identify the associated user activity, the method further comprising:

for each user activity, resetting the associated buffer when the negative criterion is met within the cadence window.

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