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(54) **FALL PREVENTION**

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Description

TECHNICAL FIELD OF THE INVENTION

5 **[0001]** The invention relates to a method and device for monitoring the motion of a user, and in particular to a method and device for determining a fall risk for a user.

BACKGROUND TO THE INVENTION

10 **[0002]** Falls affect millions of people each year and result in significant injuries, particularly in the elderly. In fact, it has been estimated that falls are one of the top three causes of death in elderly people.

[0003] A fall is defined as a sudden, uncontrolled and unintentional downward displacement of the body to the ground. There are currently some fall detection systems available that detect these falls and allow the user to obtain assistance manually or automatically if a fall occurs. Exemplary fall detectors can comprise personal help buttons (PHBs) or worn
15 and/or environment-based automatic detectors.

[0004] Automatic fall detectors comprise one or a set of sensors that measure the movement of the user, and a processor that compares the measured or processed signals with predetermined thresholds in order to detect a fall. In particular, automatic fall detectors store a set of predetermined threshold values and/or parameter sets. When the detector is activated, movement data obtained from the sensors (such as, for example, an accelerometer) will be continuously transformed and processed, and then compared with those parameter sets to determine if a fall event occurs.
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[0005] Although these fall detectors are useful, they do not actually prevent falling, and only provide a warning or alarm in the event that a user already has fallen.

[0006] However, users that are insecure during walking, for example caused or enhanced by a fear of falling, by fatigue in the muscles, by frequently multi-tasking (i.e. they are carrying items when walking, talking to their grandchild, etc, or that move in places where there is dim lighting, a wet or irregular ground surface - such as loose carpet, electricity wires, toys, tools, and other hazards) or that are under medication that may affect balance or concentration, can be assisted by a device for fall prevention that decreases the actual risk of falling, or at least alerts the user that they are at a higher risk of falling at a particular time, and makes them feel more safe.
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[0007] Document US 5,919,149 discloses fall detection based on gait analysis. Some further background information is found in DE 10 2005 004086 which describes a process for evaluating motion signals in three dimensional space and US 5,485,402 which describes a monitor that records the gait activity of a wearer.
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[0008] There is therefore a need for a method and device that can determine an instantaneous fall risk for a user.

SUMMARY OF THE INVENTION

35 **[0009]** According to a first aspect of the invention, there is provided a method of determining a fall risk of a user, the method comprising collecting measurements of the motion of the user; estimating a value for a parameter related to the gait of the user from the measurements; and determining a fall risk for the user from a comparison of the estimated value with a normal value for the parameter determined from motion of the user in which the user is at their normal risk of falling.

40 **[0010]** In a preferred embodiment, the step of determining a fall risk comprises weighting the comparison between the estimated value and the normal value according to a standard deviation of the normal value.

[0011] Preferably, the estimated value is determined from motion of the user over a period of time that is shorter than the period of time over which the normal value is determined.

[0012] In a preferred embodiment, the step of estimating comprises identifying a step boundary in the collected measurements.
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[0013] In one embodiment, the step of identifying a step boundary comprises identifying clusters of contiguous measurements in the collected measurements in which the magnitude of each of the measurements exceeds a threshold, apart from a subset of the measurements whose magnitude is less than the threshold, provided that the subset covers a time period less than a time threshold.

50 **[0014]** In another alternative embodiment, the step of identifying a step boundary comprises identifying clusters of contiguous measurements in the collected measurements, wherein the first collected measurement in the collected measurements whose magnitude exceeds a first threshold denotes the first measurement in a cluster and wherein the first collected measurement after the first measurement in the cluster whose magnitude falls below a second threshold denotes the last measurement in the cluster, provided that the last measurement is more than a minimum period after the first measurement.
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[0015] In any of these alternative embodiments, the step of identifying step boundaries can further comprise identifying the step boundary as the measurement in each cluster with the highest magnitude.

[0016] In a preferred embodiment, the parameter related to the gait of the user comprises a step size and the step of

estimating a value for the parameter comprises integrating horizontal components of the collected measurements with the integral bounds being given by consecutive identified step boundaries.

[0017] In a preferred embodiment, the step of estimating a value for the parameter comprises omitting the average velocity of the user from the integration such that the step size is determined based on the variation of the velocity.

[0018] In one embodiment, the parameter related to the gait of the user comprises, or additionally comprises, a forward step size and the step of estimating a value for the parameter comprises integrating horizontal components of the collected measurements with the integral bounds being given by consecutive identified step boundaries to give a start and end position for a step; and determining the forward step size as the norm of the vector connecting the start and end positions.

[0019] Preferably, the parameter related to the gait of the user additionally comprises a lateral step size and the step of estimating a value for the parameter further comprises defining a straight line between the start and end positions; integrating collected measurements occurring during the step to give a series of positions during the step; determining the distance between each position and the straight line; and determining the lateral step size as the maximum distance in this series.

[0020] In preferred embodiments, the method further comprises a calibration step that includes collecting measurements of the motion of the user when the user is at their normal risk of falling; and estimating the normal value for the parameter related to the gait of the user from the collected measurements.

[0021] Preferably, the step of estimating comprises estimating values for a plurality of parameters related to the gait of the user from the measurements, and the step of determining a fall risk comprises comparing the estimated values with values of the parameters determined from motion of the user in which the user is at a low risk of falling.

[0022] Preferably, the parameter or parameters related to the gait of the user is/are selected from step size, step width, step time, double support time, gait velocity, cadence, average step size, average step time, average double support time, average gait velocity and average cadence.

[0023] In accordance with a second aspect of the invention, there is provided a fall prevention device, comprising at least one sensor for collecting measurements of the motion of a user of the device; and a processor for estimating a value for a parameter related to the gait of the user from the measurements, and for determining a fall risk for the user from a comparison of the estimated value with a value of the parameter determined from motion of the user in which the user is at their normal risk of falling.

[0024] In accordance with a third aspect of the invention, there is provided a computer program product comprising computer-readable code that, when executed on a suitable computer or processor, is configured to cause the computer or processor to perform the steps in the method described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The invention will be described, by way of example only, with reference to the following drawings, in which:

Fig. 1 shows a fall prevention device according to the invention being worn by a user;

Fig. 2 shows the fall prevention device of Fig. 1 in more detail;

Fig. 3 is a flow chart illustrating the steps in a method according to the invention;

Fig. 4 is a plot illustrating measurements from an accelerometer that is in a pendant worn around a user's neck;

Fig. 5 is a plot illustrating measurements from an accelerometer that is worn on a user's ankle; and

Fig. 6 is a plot illustrating the derivative of measurements from an accelerometer that is worn on a user's ankle.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] Although the invention will be described in terms of a method and device that is used for fall prevention, it will be appreciated that the method and device can be provided with additional functionality so that the device can also be used as a fall detector.

[0027] In an example, the fall prevention device comprises a single unit that is worn by a user.

[0028] Figure 1 shows a fall prevention device 2 in the form of a pendant being worn around the neck of a user 4 and Figure 2 shows the fall prevention device 2 in more detail.

[0029] The fall prevention device 2 comprises three sensors, an accelerometer 6, a magnetometer 8 and a gyroscope 10, which are connected to a processor 12. The processor 12 receives measurements from the sensors 6, 8, 10 and processes the measurements to determine if the user 4 of the fall prevention device 2 is at a higher risk of falling.

[0030] In particular, the processor 12 processes the measurements from the accelerometer 6, magnetometer 8 and gyroscope 10 to determine the orientation of the fall prevention device 2, and processes the measurements from the accelerometer 6 (using the determined orientation) to determine parameters relating to the motion (and specifically the gait) of the user 2.

[0031] It should be understood that the three sensors are included by way of example only. Using sensor fusion, the measurements of the three sensors can complement each other for an optimal estimate of the orientation, as is known to those skilled in the art. Other sensors, for example a barometer and GPS receiver, can be added to further improve the accuracy of the parameters estimated by the device 2. It will be further appreciated that sensors can be omitted to reduce the power consumption and cost of the device 2 - for example in a minimal device 2, only the accelerometer 6 is present, in which case it is only possible to estimate the inclination of the device 2.

[0032] The fall prevention device 2 also comprises an alarm 14 that can be activated by the processor 12 to warn or notify the user 4 that they are at an increased risk of falling. The alarm 14 can also comprise (or be replaced by) some means that provides the user 4 with an indication of their current risk of falling, even if they are not currently at a high risk of falling. For example, the fall prevention device 2 could be provided with means for providing vibrotactile or auditory feedback, or with a series of lights (or a light that can show different colors) which can be illuminated to indicate the current fall risk (for example there could be lights associated with the user 4 being at low, medium and high risk of falling).

[0033] The fall prevention device 2 also comprises transmitter circuitry 16 that allows the fall prevention device 2 to transmit an alarm or warning signal to a base station associated with the fall prevention device 2 (which can then issue an alarm or summon help from a healthcare provider or the emergency services). The base station can also carry out further processing of the sensor measurements, and/or store the sensor measurements for later analysis. In alternative examples the transmitter circuitry 16 may be omitted if the fall prevention device 2 does not need to contact a base station to issue an alarm or summon help from a healthcare provider (for example if the fall prevention device 2 can contact the healthcare provider by using sound).

[0034] In other examples (not represented by the device 2 shown in Figure 2), the fall prevention device 2 can include a memory unit for storing the sensor measurements for later analysis.

[0035] It is known that a large variance in gait parameters (i.e. parameters associated with the gait of a user) corresponds to a high risk of falling. However, this is a static relationship; the variance is an average obtained during general walking, and is related to an average risk of falling, which does not necessarily provide any information about the current risk of falling for the user 4. Gait parameters can include measures such as step size, step width, step time, double support time (i.e. the time that both feet are in contact with the ground), gait velocity, and cadence. The gait parameters can also include averages of the above measures over a few steps, so for example an average step size, average step width, average step time, average double support time, average gait velocity and average cadence.

[0036] In accordance with the invention, the fall prevention device 2 determines values for gait parameters from sensor measurements covering a short period of time and compares these values with normal values for the user 4 (i.e. values that are obtained when the user 4 is at their normal (i.e. preferably a low or minimal) risk of falling). In particular, the fall prevention device 2 can determine various gait parameters from sensor measurements covering, say, 12 steps (so 6 strides). The normal values for the user 4 can be obtained by collecting measurements while the user 4 is walking steadily for a period of time (for example a minute) or for a certain number of steps (for example 40 steps).

[0037] A method of determining a dynamic risk of falling in accordance with the invention is shown in Figure 3. In step 101, the sensors 6, 8, 10 take measurements of the motion of the user 4 and in step 103, the processor 12 estimates values for the required gait parameters from the measurements. In step 105, the processor 12 then compares these estimates to usual values of these gait parameters for the user 4 to determine the user's dynamic risk of falling. As indicated above, the usual values correspond to those observed when the user 4 is at their normal (i.e. preferably a minimal or low) risk of falling.

[0038] The normal or usual values for the gait parameters can be obtained during a calibration session before the fall prevention device 2 is used (for example the user 4 can wear the fall prevention device 2 while it is in a calibration mode, and the fall prevention device 2 can determine values for each gait parameter while the user 4 is walking normally).

[0039] In a preferred embodiment of the invention, the comparison between the estimated values and the normal values is weighted according to the standard deviation of the normal gait parameter values.

[0040] For example, if μ represents the calibration mean (i.e. the mean of the normal values for a particular parameter), σ represents the standard deviation in that calibration mean, and a represents the currently observed parameter value, a deviation is signaled if

$$\frac{|a - \mu|}{\sigma} \quad (1)$$

exceeds a threshold.

[0041] For example,

$$\exp\left[-\frac{(a-\mu)^2}{2\sigma^2}\right] \quad (2)$$

5 maps to a value between 0 and 1, where 1 indicates normal gait (for that user), and a deviation from normal gait is signaled (i.e. the user is at a higher risk of falling) if the result falls below a threshold, for example 0.7.

[0042] It will be appreciated that the values for μ and σ are usually dependent on the user and will need to be set independently for each user.

10 [0043] In one embodiment of the invention, the processor 12 estimates values for an average step size and an average step width. However, in other examples of the invention, other combinations of gait parameters can be used.

[0044] The operation of the processor 12 in determining estimates for specific gait parameters will be described further below. As it will be shown, in the example in which the fall prevention device 2 is a pendant located around the neck of the user 4, the way in which the averages a and μ are calculated relates them to the variance in step size rather than to the mean, as will be explained further below. Thus, the invention effectively compares current and normal variances. It should be noted that a is typically averaged over a shorter period than μ .

15 [0045] In addition, although in an example the fall prevention device 2 is in the form of a pendant to be worn around the neck of a user 4, it will be appreciated that the invention can be implemented in alternative forms that are to be worn on different parts of the body of the user 4, such as at the waist or on the ankle of the user 4. As described further below, in these examples it is necessary to modify the processing used to determine the gait parameters from the sensor measurements.

[0046] Moreover, depending on the particular gait parameters that the processor 12 determines from the sensor measurements (and if the movements of the user 4 do not cause fast rotations of the fall prevention device 2), the gyroscope 10, the magnetometer 8 or both the magnetometer 8 and gyroscope 10 can be omitted from the device 2. In the examples in which the fall prevention device 2 is a pendant, it has been found that the gait variation estimate is less sensitive without the gyroscope 10, but it is still capable of detecting deviations from the normal gait.

Estimating the step size

25 [0047] In order to obtain an estimate of the step size, a number of processing steps are required. In particular, it is necessary to estimate the step boundaries and the orientation of the accelerometer (so that the accelerometer measurements can be transformed to Earth coordinates) in order to estimate the step or stride size.

30 [0048] Estimating step boundaries - It is important to accurately estimate step boundaries (which are defined as the moment of heel strike (HS), i.e. when the swing leg is touching the ground again, starting the stance phase), since missing a boundary will cause a significant deviation in a , hence leading to an alarm.

[0049] Step boundaries can also be used to estimate stepping time, which is another gait parameter, and, when combined with step size, allows an estimate of walking velocity to be determined.

35 [0050] For accelerometers that are rigidly attached to the upper body of a user, step boundaries are usually found by observing the 'zero' crossing of the vertical acceleration. Of course, it will be appreciated that the actual "crossing" will be through 1g (9.81ms⁻²) since gravity is always acting on the user. The vertical acceleration will be known after the orientation of the accelerometer is determined - although for rigidly mounted accelerometers, the accelerometer reading along the coordinate axis corresponding to vertical usually provides a sufficient approximation.

40 [0051] However, in the example in which the fall prevention device 2 is in the form of a pendant, the fall prevention device 2 (and therefore the accelerometer 6) is free to move relative to the user 4, which means that the accelerometer coordinate system also moves relative to the user 4.

[0052] Therefore, it is preferred to modify the detection of step boundaries (i.e. heel strikes) as follows. Firstly, the norm of the signal from the accelerometer 6 is calculated. Then, the peaks in this signal serve as boundary markers for each step, which closely link to the heel strike (HS), as shown in Figure 4.

[0053] The peaks are found using a two-step procedure. First, so-called clusters are identified. Second, the maximum value in each cluster is identified as the step boundary. The clusters are found as the range of samples that are above a certain threshold (typically 2 ms⁻² above gravity, i.e. ~12 ms⁻²), where a small gap of samples not surpassing that threshold is permitted (typically 0.3 times a typical step time (which is around 0.5 seconds), i.e. 0.15 sec).

50 [0054] This algorithm works for accelerometers 6 that are attached to the upper body of the user 4. If the accelerometer 6 is attached at or to the lower body of the user 4 (for example the ankle), then usually two clusters appear per step, or actually per stride, as shown in Figure 5. Since the accelerometer signal is observed at the ankle, the period of a stride (i.e. a step with both the left foot and the right foot) is seen.

55 [0055] One cluster corresponds to the lifting of the foot, and the other corresponds to the heel strike. It can be difficult to decide which of the two is the heel strike. However, it can also be observed that a single minimum occurs per step, and this can be used instead for detecting the step boundaries.

[0056] Figure 5 also shows another way to identify the clusters. Instead of a single threshold (with a small gap being

permitted), two thresholds are used. They introduce a hysteresis - surpassing one threshold indicates the start of a cluster, and falling below the second threshold indicates the end of a cluster, provided that the measurements fall below the second threshold after a minimum duration from the first measurement in the cluster. Preferably, the minimum duration is derived from the step time, as described above.

5 **[0057]** The unique minimum shown for each stride in Figure 5 corresponds to the swing phase and it is less favorable to use this as the step boundary. Instead, it is preferable to use the heel strike as the step boundary for several reasons. Firstly, this is a clearly defined event. Secondly, when measuring at the feet or ankle, at heel strike the velocity relative to the ground is zero, which can be used in estimating the movement. Thirdly, at heel strike, the acceleration in the horizontal direction is low, which leads to lower errors when (double) integrating the acceleration for estimating the step size. The sample values at the beginning of the integration have a large influence on the outcome, so large values can cause a bias in the total outcome.

10 **[0058]** A better algorithm for detecting step boundaries when the accelerometer 6 is located on the lower body of the user 4 is found by observing the derivative of the acceleration, as shown in Figure 6. The boundaries are more clear, and they associate with the heel strike event.

15 **[0059]** It will be appreciated that as different algorithms can be used for different fall prevention device 2 locations on the user's body, the processor 12 in the fall prevention device 2 needs to know the location used. The user 4 may be able to select an appropriate location from a list of locations offered by the processor 12, or, alternatively, the processor 12 can execute a classifier algorithm to detect the location (and therefore the algorithm to use to detect the step boundary) based on the particular patterns in the measurements of the accelerometer 6.

20 **[0060]** Estimating accelerometer orientation - The orientation of the accelerometer 6 (and therefore the fall prevention device 2) can be estimated from the direction that gravity appears in the accelerometer coordinate system. By defining the z-axis to correspond with the vertical direction when the accelerometer 6 is not tilted, the orientation follows through the vector dot product of the measured gravity direction and the z-axis, i.e. through the z-component of the measured gravity (as is known, when using normalized values, the dot product equals the cosine of the enclosed angle).

25 **[0061]** Since the accelerometer 6 is sensitive to both acceleration due to gravity and acceleration due to movement, a filter is needed in order to estimate which component is due to gravity. Usually, a gyroscope 10 is added to measure the angular rotation speed and to correct the measured acceleration correspondingly. However, if the movements of the user 4 do not cause fast rotations of the fall prevention device 2, the gyroscope 10 can be omitted.

30 **[0062]** Without fast rotations, the gravity component can be found as the low-pass filtered component of the signal from the accelerometer 6. Since causality constraints in the filter design introduce a delay, the filtered acceleration signal needs to be corrected for this delay.

35 **[0063]** From the measured direction of gravity, the inclination or orientation of the fall prevention device 2 can be estimated. However, this inclination or orientation does not provide information about the horizontal direction of the device 2 (i.e. which way the device 2 is facing), so the magnetometer 8 can be used to determine the horizontal orientation of the device 2. Gyroscopes can also be used in the estimation of horizontal orientation.

40 **[0064]** Orientation can be expressed in different ways, of which Euler angles and Euler parameters are the most commonly used. They are usually implemented through matrices or quaternions. The algebras are isomorphic, and provide a way to transform the measured values (acceleration etc.) as expressed in the accelerometer's local coordinate system to the global (Earth) coordinate system.

45 **[0065]** Estimating step or stride sizes - Once the acceleration signals have been transformed to the Earth coordinate system, the step sizes can be computed by double integrating (with respect to time) the horizontal components of these transformed signals. The boundaries for the integrations are given by the estimated step boundaries. The integration constants, velocity and position at the beginning of the step, are both set to zero.

[0066] For the position this is fine, since the step size is needed, which is the difference between end and start position.

50 **[0067]** For the velocity this is correct in the case that the device 2 is located on a foot of the user 4, since upon heel strike the velocity relative to the Earth is zero. However, when the device 2 is located on the upper body of the user 4, for example when the device 2 is a pendant, there will be a near constant velocity. Therefore, setting the velocity to zero at each step boundary will introduce errors, since a constant velocity yields a larger step size estimate. However, if it is assumed that the velocity is constant during the period of observation, i.e. during the averaging period (typically around 10-12 steps for determining a , and around 30-60 seconds for determining μ), the constant velocity component can be omitted. This means that the step size can be computed based on the variation in the velocity, which means that the device 2 (and the estimated fall risk) will become independent of the current walking speed - only the deviations will be observed.

55 **[0068]** The step size p follows as the integral of velocity v over step time:

$$p = \int_{HS_0}^{HS_1} v \, dt = \bar{v}(HS_1 - HS_0) + \int_{HS_0}^{HS_1} \Delta v \, dt \quad (3)$$

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where HS_0 and HS_1 are the times of subsequent heel strikes (HS) and \bar{v} and Δv denote the average velocity and its deviation respectively.

[0069] Defining the step time $T = HS_1 - HS_0 = \bar{T} + \Delta T$, and $p = \bar{p} + \Delta p$, where $\bar{p} = \bar{v}\bar{T}$, the deviation in step size follows as:

5

$$\Delta p = \bar{v}\Delta T + \int_{HS_0}^{HS_1} \Delta v dt \quad (4)$$

10

[0070] It should be noted that, by definition, the mean of $(\Delta p)^2$ equals the variance of p . The velocity deviation Δv can be computed from the measured acceleration through:

15

$$\Delta v(t) = \Delta v(HS_0) + \int_{HS_0}^t a dt' \quad (5)$$

At constant walking velocity,

20

$$\int_{HS_0}^{HS_1} a dt \approx 0 \quad (6)$$

and it is reasonable to assume that $\Delta v(HS_0)$ is roughly the same at each step. Then, by neglecting the first term in equation (4) above, Δp is approximated as:

25

$$\Delta p \approx \int_{HS_0}^{HS_1} \Delta v(HS_0) dt + \int_{HS_0}^{HS_1} dt \int_{HS_0}^t a dt' = \Delta v(HS_0)(HS_1 - HS_0) + \int_{HS_0}^{HS_1} dt \int_{HS_0}^t a dt' = \mu + \Delta s \quad (7)$$

30

[0071] The second term, Δs , is the result of the double integration of the acceleration when using zero integration constants. Since, by definition, $E[\Delta p] = 0$, it follows that

$$\mu = -E[\Delta s] \quad (8)$$

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[0072] So, a first order approximation of μ can be obtained by observing the (horizontal) acceleration under stable walking conditions and computing the mean of the double integrated acceleration. This process also yields a standard deviation:

40

$$\mu_0 = \text{mean}(\Delta s_{\text{stable}}) \quad (9)$$

$$\sigma_0 = \text{std}(\Delta s_{\text{stable}}) \quad (10)$$

45

So, μ_0 estimates $-\mu$, and the variance of p follows as

$$\text{var}(p) = E[(\Delta p)^2] = \mu^2 + \mu_0^2 + \sigma_0^2 \quad (11)$$

50

[0073] In typical cases, $\sigma_0^2 \ll \mu_0^2$ and $\text{var}(p) \approx 2\mu^2$. During operation, a running estimate $a = E[\Delta s]$ is made over a few steps, and is compared with μ_0 relative to σ_0 , see equation (1). So, although mean values are compared, they basically reflect variance in the step sizes.

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[0074] The values μ_0 and σ_0 are user dependent and need to be set for each user in a calibration phase. Note, however, that since the average velocity \bar{v} is not accounted for in the calculations, the method is insensitive to the actual walking speed of the user 4.

[0075] The first term $\bar{v}\Delta T$ in the expression for Δp above has been neglected and introduces an error. It is proportional to the average velocity and the deviation in step time. As a refinement, it could be included in the estimate of Δp .

[0076] Since the orientation estimate contains errors, there is always some form of gravity leakage into the horizontal accelerations (i.e. the horizontal accelerations will include some component due to gravity) and double integration may induce large errors in the estimated step size. One way to suppress this leakage is by band-pass filtering (or high-pass filtering) the signals from the accelerometer 6, preferably using a linear phase filter so that the wave form of the signal is maintained. Typical cut-off frequencies are 0.1 Hz and 20-40 Hz (where the actual application of the upper cut-off frequency also depends on the used sampling frequency). This band-pass filtering is not required.

[0077] A measure that has been found to be particularly effective is the de-trending per integration interval (step or stride) of the acceleration. This amounts to requiring that the average acceleration (from the start heel strike to the end heel strike) is zero. In other words, the velocity after integration equals the velocity at the start of integration (which is zero). The de-trended acceleration is obtained by subtracting the integrated acceleration, divided by the step duration, from the measured acceleration. The de-trended acceleration is used to compute the step size as described above.

[0078] Assuming no errors in the coordinate system transformation, for example due to inhomogeneity in the direction and size of the geomagnetic field, this integration yields the direction of a step in terms of north-south and east-west. However, for gait stability it is necessary to examine the motion in forward and lateral directions. This is solved in the following way.

[0079] The start position (which is the origin, by definition) and the end position are computed as explained above. Their difference spans a 2D vector in the horizontal plane. Then, the forward step size is defined as the norm of this 2D vector, i.e. as the distance of the end position from the start position (it should be noted that, as a consequence, the above Δp are always positive). Subsequently, a straight line is defined between the start position and the end position and the distance is determined between this line and each point from the double integration of the accelerometer measurements during the step. The maximum distance in this series is taken as the lateral step size.

[0080] Step time follows as the duration between the estimated step boundaries, and velocity as the ratio between step size and step time (in the event that the device 2 is located on a foot of the user 4).

[0081] While stride sizes are computed when the device 2 is on the lower body of the user 4, step size can be computed when the device 2 is on the upper body of the user 4, yielding twice as fast an average.

[0082] It will be appreciated by those skilled in the art that alternative methods for determining step size can be used that do not require the double integration of the horizontal acceleration measurements. These methods include the inverted pendulum model [Zijlstra & Hof, Displacement of the pelvis during human walking, Gait and Posture 6, 1997, 249- 267] and the 4th power root of the difference between maximum and minimum vertical acceleration [Weinberg, Using the ADXL202 in Pedometer and Personal Navigation Applications, Application Note AN-602, Analog Devices, 2002].

[0083] Although an example has been described in terms of a pendant to be worn around the neck of a user 4, it will be appreciated that the invention can be implemented in alternative forms that are to be worn on different parts of the body of the user 4. Of course, in these examples, it will be necessary to modify the processing used to determine the gait parameters from the sensor measurements, but these modifications will be readily apparent to a person skilled in the art based on the description provided above.

[0084] In the example described with reference to Figure 2, the collection and processing of the sensor measurements is performed in a single unit. However, in alternative examples the processing of the measurements can be performed in a unit that is remote from the sensors, in which case the fall prevention device 2 will comprise a sensor unit to be worn by the user 4 that transmits the sensor measurements to the remote unit. In this example there is no need for the sensor unit to include a dedicated processor.

[0085] There is therefore provided a method and device that can determine an instantaneous fall risk for a user.

[0086] It will be appreciated that the algorithms described above that are used to determine various gait parameters can be used in applications other than fall prevention. For example, they can be used in activity monitoring and fitness applications such as endurance coaching (for example to support the keeping of cadence during jogging). The algorithms may be used in step counters or devices that support injury prevention, for example during jogging. Further the algorithms may be used in a device or system that uses gait parameters as a biometric for identifying an individual.

[0087] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is defined by the claims.

[0088] Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps. A single processor or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A method of determining a fall risk of a user, the method comprising:

5 collecting measurements of the motion of the user using a sensor;
 estimating a value for a parameter related to the gait of the user from the measurements using a processor; and
 determining a fall risk for the user, using the processor, from a comparison of the estimated value with a normal
 value for the parameter determined from motion of the user in which the user is at their normal risk of falling;
characterized in that
 10 the step of estimating comprises identifying a step boundary in the collected measurements by:

(i) identifying clusters of contiguous measurements in the collected measurements in which the magnitude
 of each of the measurements exceeds a threshold, apart from a gap in the measurements, wherein the
 magnitudes of the measurements in the gap are less than the threshold, provided that the gap covers a
 15 time period less than a time threshold; or
 (ii) identifying clusters of contiguous measurements in the collected measurements, wherein the first col-
 lected measurement in the collected measurements whose magnitude exceeds a first threshold denotes
 the first measurement in a cluster and wherein the first collected measurement after the first measurement
 in the cluster whose magnitude falls below a second threshold denotes the last measurement in the cluster,
 20 provided that the last measurement is more than a minimum period after the first measurement.

2. A method as claimed in claim 1, wherein the step of determining a fall risk comprises weighting the comparison
 between the estimated value and the normal value according to a standard deviation of the normal value.

25 3. A method as claimed in claim 1 or 2, wherein the estimated value is determined from motion of the user over a
 period of time that is shorter than the period of time over which the normal value is determined.

4. A method as claimed in claim 1, wherein the step of identifying step boundaries further comprises identifying the
 step boundary as the measurement in each cluster with the highest magnitude.

30 5. A method as claimed in claim 1, wherein the step of identifying step boundaries further comprises identifying the
 step boundary as a minimum between two consecutive identified clusters.

35 6. A method as claimed in any preceding claim, wherein the parameter related to the gait of the user comprises a step
 size and the step of estimating a value for the parameter comprises integrating horizontal components of the collected
 measurements with the integral bounds being given by consecutive identified step boundaries.

40 7. A method as claimed in claim 6, wherein the step of estimating a value for the parameter comprises computing a
 double integration with respect to time of the horizontal components of the collected measurements relating to
 acceleration, the integration constants being set to zero at the beginning of the step.

8. A method as claimed in any preceding claim, wherein the parameter related to the gait of the user comprises, or
 additionally comprises, a forward step size and the step of estimating a value for the parameter comprises:
 45 integrating horizontal components of the collected measurements with the integral bounds being given by
 consecutive identified step boundaries to give a start and end position for a step; and
 determining the forward step size as the norm of the vector connecting the start and end positions.

50 9. A method as claimed in claim 7 or 8, wherein the parameter related to the gait of the user additionally comprises a
 lateral step size and the step of estimating a value for the parameter further comprises:
 defining a straight line between the start and end positions;
 integrating collected measurements occurring during the step to give a series of positions during the step;
 determining the distance between each position and the straight line; and
 55 determining the lateral step size as the maximum distance in this series.

10. A method as claimed in any preceding claim, further comprising a calibration step that includes:

collecting measurements of the motion of the user when the user is at their normal risk of falling; and estimating the normal value for the parameter related to the gait of the user from the collected measurements.

11. A fall prevention device, comprising:

at least one sensor for collecting measurements of the motion of a user of the device; and a processor for estimating a value for a parameter related to the gait of the user from the measurements, and for determining a fall risk for the user from a comparison of the estimated value with a value of the parameter determined from motion of the user in which the user is at their normal risk of falling
characterized in that the processor is configured to estimate the value for a parameter related to the gait of the user by identifying a step boundary in the collected measurements by:

(i) identifying clusters of contiguous measurements in the collected measurements in which the magnitude of each of the measurements exceeds a threshold, apart from a gap in the measurements, wherein the magnitudes of the measurements in the gap are less than the threshold, provided that the gap covers a time period less than a time threshold; or

(ii) identifying clusters of contiguous measurements in the collected measurements, wherein the first collected measurement in the collected measurements whose magnitude exceeds a first threshold denotes the first measurement in a cluster and wherein the first collected measurement after the first measurement in the cluster whose magnitude falls below a second threshold denotes the last measurement in the cluster, provided that the last measurement is more than a minimum period after the first measurement.

12. A computer program product comprising computer-readable code that, when executed on a suitable computer or processor, is configured to cause the computer or processor to perform the steps in the method defined in any one of claims 1 to 10.

Patentansprüche

1. Verfahren zum Bestimmen eines Sturzrisikos eines Benutzers, wobei das Verfahren umfasst:

Erfassen von Messungen der Bewegung des Benutzers unter Verwendung eines Sensors; Schätzen eines Werts für einen mit dem Gang des Benutzers in Verbindung stehenden Parameter anhand der Messungen unter Verwendung eines Prozessors; und Bestimmen eines Sturzrisikos für den Benutzer unter Verwendung des Prozessors anhand eines Vergleichs des geschätzten Werts mit einem normalen Wert für den anhand der Bewegung des Benutzers bestimmten Parameter, bei dem für den Benutzer ein normales Sturzrisiko besteht;
dadurch gekennzeichnet, dass
 der Schritt des Schätzens das Identifizieren einer Schrittgrenze in den erfassten Messungen umfasst durch:

(i) Identifizieren von Clustern angrenzender Messungen in den erfassten Messungen, bei denen die Magnitude einer jeder der Messungen einen Schwellwert überschreitet, abgesehen von einer Lücke in den Messungen, wobei die Magnituden der Messungen in der Lücke geringer sind als der Schwellwert, vorausgesetzt die Lücke deckt eine Zeitspanne ab, die geringer ist als ein Zeitschwellwert; oder

(ii) Identifizieren von Clustern angrenzender Messungen in den erfassten Messungen, wobei die erste erfasste Messung in den erfassten Messungen, deren Magnitude einen ersten Schwellwert überschreitet, die erste Messung in einem Cluster kennzeichnet, und wobei die erste erfassten Messung nach der ersten Messung im Cluster, deren Magnitude unter einen zweiten Schwellwert fällt, die letzte Messung im Cluster kennzeichnet, vorausgesetzt die letzte Messung ist mehr als eine Mindestspanne nach der ersten Messung.

2. Verfahren nach Anspruch 1, wobei der Schritt des Bestimmens eines Sturzrisikos das Gewichten des Vergleichs zwischen dem geschätzten Wert und dem normalen Wert nach einer Standardabweichung vom normalen Wert umfasst.

3. Verfahren nach Anspruch 1 oder 2, wobei der geschätzte Wert aus der Bewegung des Benutzers über eine Zeitspanne bestimmt wird, die kürzer ist als die Zeitspanne über die der normale Wert bestimmt wird.

4. Verfahren nach Anspruch 1, wobei der Schritt des Identifizierens von Schrittgrenzen weiter das Identifizieren der

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Schrittgrenze als die Messung in jedem Cluster mit der höchsten Magnitude umfasst.

5 5. Verfahren nach Anspruch 1, wobei der Schritt des Identifizierens von Schrittgrenzen weiter das Identifizieren der Schrittgrenze als ein Minimum zwischen zwei aufeinanderfolgend identifizierten Clustern umfasst.

10 6. Verfahren nach einem der vorstehenden Ansprüche, wobei der mit dem Gang des Benutzers in Verbindung stehende Parameter eine Schrittgröße umfasst, und der Schritt des Schätzens eines Werts für den Parameter das Integrieren von horizontalen Komponenten der erfassten Messungen umfasst, wobei die integralen Grenzen durch aufeinanderfolgend identifizierte Schrittgrenzen gegeben sind.

15 7. Verfahren nach Anspruch 6, wobei der Schritt des Schätzens eines Werts für den Parameter das Berechnen einer doppelten Integration in Bezug auf Zeit der horizontalen Komponenten der erfassten Messungen im Verhältnis zu Beschleunigung umfasst, wobei die Integrationskonstanten bei Beginn des Schritts auf null gesetzt werden.

20 8. Verfahren nach einem der vorstehenden Ansprüche, wobei der mit dem Gang des Benutzers in Verbindung stehende Parameter eine Schrittgröße nach vorwärts umfasst oder zusätzlich umfasst, und der Schritt des Schätzens eines Werts für den Parameter umfasst:

20 Integrieren horizontaler Komponenten der erfassten Messungen, wobei die integralen Grenzen durch aufeinanderfolgend identifizierte Schrittgrenzen gegeben sind, um eine Start- und Endposition für einen Schritt zu ergeben; und

Bestimmen der Schrittgröße nach vorwärts als die Norm des Vektors, der die Start- und Endposition verbindet.

25 9. Verfahren nach Anspruch 7 oder 8, wobei der mit dem Gang des Benutzers in Verbindung stehende Parameter zusätzlich eine seitliche Schrittgröße umfasst, und der Schritt des Schätzens eines Werts für den Parameter weiter umfasst:

30 Definieren einer geraden Linie zwischen der Start- und Endposition;

Integriere erfasster Messungen, die während des Schritts stattfinden, um eine Reihe von Positionen während des Schritts zu ergeben;

Bestimmen des Abstands zwischen jeder Position und der geraden Linie;

und

Bestimmen der seitlichen Schrittgröße als maximaler Abstand in dieser Serie.

35 10. Verfahren nach einem der vorstehenden Ansprüche, weiter umfassend einen Kalibrierungsschritt, der enthält:

Erfassen von Messungen der Bewegung des Benutzers, wenn für den Benutzer ein normales Sturzrisiko besteht; und

40 Schätzen des normalen Werts des mit dem Gang des Benutzers in Verbindung stehenden Parameters anhand der erfassten Messungen.

11. Vorrichtung zur Sturzvermeidung, umfassend:

45 mindestens einen Sensor zum Erfassen von Messungen der Bewegung eines Benutzers der Vorrichtung; und einen Prozessor zum Schätzen eines Werts für einen mit dem Gang des Benutzers in Verbindung stehenden Parameters anhand der Messungen, und zum Bestimmen eines Sturzrisikos für den Benutzer anhand eines Vergleichs des geschätzten Werts mit einem Wert des Parameters, der anhand der Bewegung des Benutzers bestimmt wird, in der für den Benutzer ein normales Sturzrisiko besteht,

dadurch gekennzeichnet, dass

50 der Prozessor konfiguriert ist, um den Wert für einen mit dem Gang des Benutzers in Verbindung stehenden Parameter durch Identifizieren einer Schrittgrenze in den erfassten Messungen zu schätzen durch:

55 (i) Identifizieren von Clustern angrenzender Messungen in den erfassten Messungen, bei denen die Magnitude einer jeder der Messungen einen Schwellwert überschreitet, abgesehen von einer Lücke in den Messungen, wobei die Magnituden der Messungen in der Lücke geringer sind als der Schwellwert, vorausgesetzt die Lücke deckt eine Zeitspanne ab, die geringer ist als ein Zeitschwellwert; oder

(ii) Identifizieren von Clustern angrenzender Messungen in den erfassten Messungen, wobei die erste erfasste Messung in den erfassten Messungen, deren Magnitude einen ersten Schwellwert überschreitet,

die erste Messung in einem Cluster kennzeichnet, und wobei die erste erfassten Messung nach der ersten Messung im Cluster, deren Magnitude unter einen zweiten Schwellwert fällt, die letzte Messung im Cluster kennzeichnet, vorausgesetzt die letzte Messung ist mehr als eine Mindestspanne nach der ersten Messung.

- 5 12. Computerprogrammprodukt, umfassend computerlesbaren Code, der, wenn er auf einem geeigneten Computer oder Prozessor ausgeführt wird, konfiguriert ist, um zu verursachen, dass der Computer oder Prozessor die Schritte in dem in einem der Ansprüche 1 bis 10 definierten Schritte vornimmt.

10 **Revendications**

1. Procédé de détermination d'un risque de chute d'un utilisateur, le procédé comprenant les étapes consistant à :

recueillir des mesures du mouvement de l'utilisateur en utilisant un capteur ;

15 estimer une valeur pour un paramètre en rapport avec la démarche de l'utilisateur à partir des mesures en utilisant un processeur ; et

déterminer un risque de chute pour l'utilisateur en utilisant le processeur à partir d'une comparaison de la valeur estimée avec une valeur normale pour le paramètre déterminé à partir du mouvement de l'utilisateur, dans lequel l'utilisateur est à son risque normal de chute ;

20 **caractérisé en ce que**

l'étape d'estimation comprend l'identification d'une limite de pas dans les mesures recueillies par :

(i) identification de groupes de mesures contiguës dans les mesures recueillies, dans lequel la grandeur de chacune des mesures dépasse un seuil, en dehors d'un espacement dans les mesures, dans lequel les grandeurs des mesures dans l'espacement sont inférieures au seuil, pourvu que l'espacement couvre une période de temps inférieure à un seuil de temps ; ou

25

(ii) identification de groupes de mesures contiguës dans les mesures recueillies, dans lequel la première mesure recueillie dans les mesures recueillies dont la grandeur dépasse un premier seuil désigne la première mesure d'un groupe et dans lequel la première mesure recueillie après la première mesure du groupe dont la grandeur chute en dessous d'un second seuil désigne la dernière mesure du groupe, pourvu que la dernière mesure soit supérieure à une période minimale après la première mesure.

30

2. Procédé selon la revendication 1, dans lequel l'étape de détermination d'un risque de chute comprend la pondération de la comparaison entre la valeur estimée et la valeur normale conformément à un écart type de la valeur normale.

35

3. Procédé selon la revendication 1 ou 2, dans lequel la valeur estimée est déterminée à partir du mouvement de l'utilisateur sur une période de temps qui est plus courte que la période de temps sur laquelle la valeur normale est déterminée.

- 40 4. Procédé selon la revendication 1, dans lequel l'étape d'identification de limites de pas comprend en outre l'identification de la limite de pas comme mesure dans chaque groupe ayant la grandeur la plus élevée.

- 45 5. Procédé selon la revendication 1, dans lequel l'étape d'identification de limites de pas comprend en outre l'identification de la limite de pas comme minimum entre deux groupes consécutifs identifiés.

6. Procédé selon l'une quelconque des revendications précédentes, dans lequel le paramètre en rapport avec la démarche de l'utilisateur comprend une taille de pas et l'étape d'estimation d'une valeur pour le paramètre comprend l'intégration de composantes horizontales des mesures recueillies avec les limites intégrales qui sont données par les limites de pas consécutives identifiées.

50

7. Procédé selon la revendication 6, dans lequel l'étape d'estimation d'une valeur pour le paramètre comprend le calcul d'une double intégration par rapport au temps des composantes horizontales des mouvements recueillies en rapport avec l'accélération, les constantes d'intégration étant réglées à zéro au début de l'étape.

- 55 8. Procédé selon l'une quelconque des revendications précédentes, dans lequel le paramètre en rapport avec la démarche de l'utilisateur comprend ou comprend en plus une taille de pas en avant et l'étape d'estimation d'une valeur pour le paramètre comprend :

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l'intégration de composantes horizontales des mesures recueillies avec les limites intégrales qui sont données par les limites de pas consécutives identifiées pour donner une position de départ et de fin pour un pas ; et la détermination de la taille de pas en avant comme la norme du vecteur raccordant les positions de départ et de fin.

5

9. Procédé selon la revendication 7 ou 8, dans lequel le paramètre en rapport avec la démarche de l'utilisateur comprend en outre une taille de pas latéral et l'étape d'estimation d'une valeur pour le paramètre comprend en outre :

10

la définition d'une ligne droite entre les positions de départ et de fin ;
l'intégration de mesures recueillies se produisant au cours du pas pour donner une série de positions au cours du pas ;
la détermination de la distance entre chaque position et la ligne droite ; et
la détermination de la taille de pas latéral comme la distance maximale de cette série.

15

10. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre une étape d'étalonnage qui inclut :

20

le recueil de mesures du mouvement de l'utilisateur lorsque l'utilisateur est à son risque normal de chute ; et l'estimation de la valeur normale pour le paramètre en rapport avec la démarche de l'utilisateur à partir des mesures recueillies.

11. Dispositif de prévention de chute comprenant :

25

au moins un capteur pour recueillir des mesures du mouvement d'un utilisateur du dispositif ; et un processeur pour estimer une valeur pour un paramètre en rapport avec la démarche de l'utilisateur à partir des mesures et pour déterminer un risque de chute pour l'utilisateur à partir d'une comparaison de la valeur estimée avec une valeur du paramètre déterminée à partir du mouvement de l'utilisateur dans lequel l'utilisateur est à son risque normal de chute,

30

caractérisé en ce que

le processeur est configuré pour estimer la valeur pour un paramètre en rapport avec la démarche de l'utilisateur en identifiant une limite de pas dans les mesures recueillies par :

35

(i) identification de groupes de mesures contiguës dans les mesures recueillies, dans lequel la grandeur de chacune des mesures dépasse un seuil, en dehors d'un espacement dans les mesures, dans lequel les grandeurs des mesures dans l'espacement sont inférieures au seuil, pourvu que l'espacement couvre une période de temps inférieure à un seuil de temps ; ou

40

(ii) identification de groupes de mesures contiguës dans les mesures recueillies, dans lequel la première mesure recueillie dans les mesures recueillies dont la grandeur dépasse un premier seuil désigne la première mesure d'un groupe et dans lequel la première mesure recueillie après la première mesure du groupe dont la grandeur chute en dessous d'un second seuil désigne la dernière mesure du groupe, pourvu que la dernière mesure soit supérieure à une période minimale après la première mesure.

45

12. Produit de programme informatique comprenant un code lisible par ordinateur qui, lorsqu'il est exécuté sur un ordinateur ou un processeur approprié, est configuré pour amener l'ordinateur ou le processeur à effectuer les étapes du procédé définies selon l'une quelconque des revendications 1 à 10.

50

55

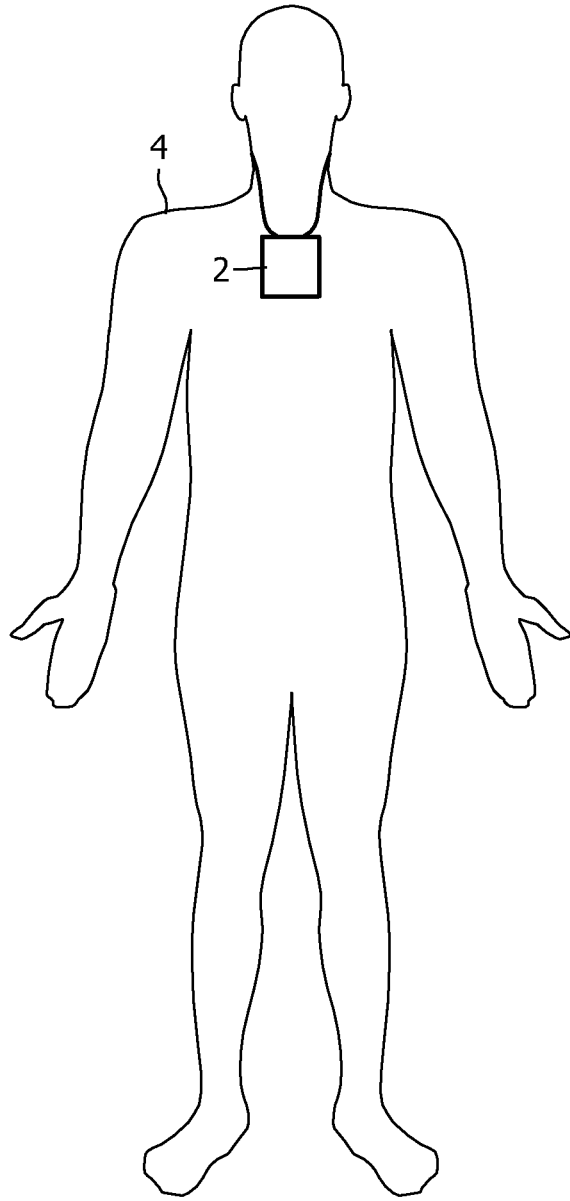


FIG. 1

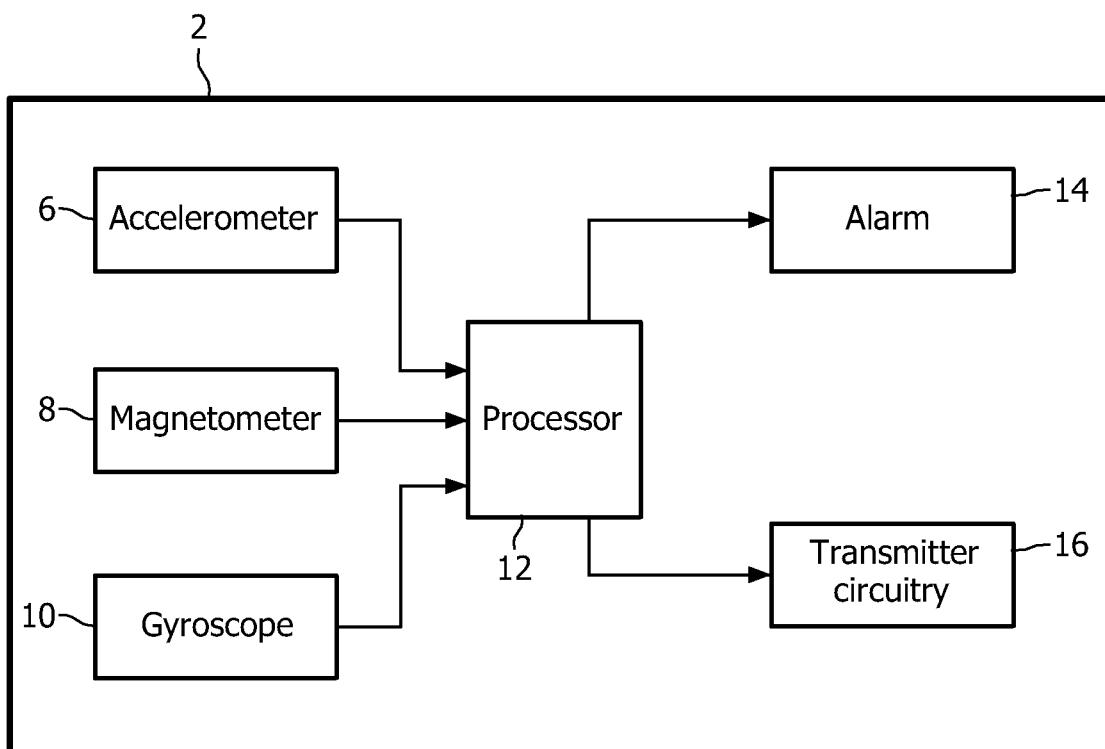


FIG. 2

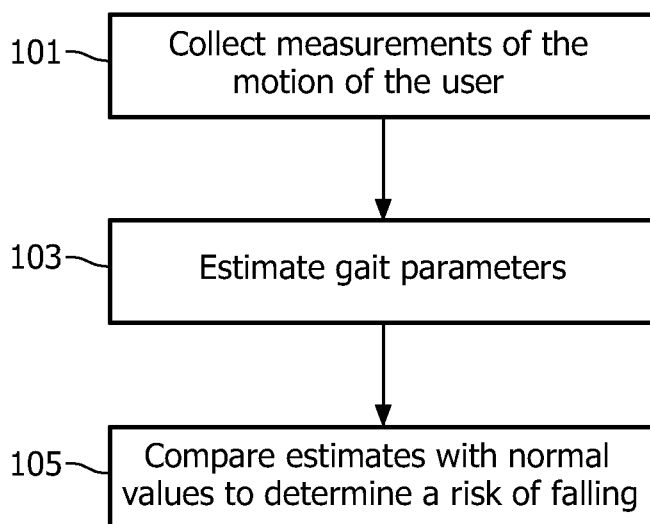


FIG. 3

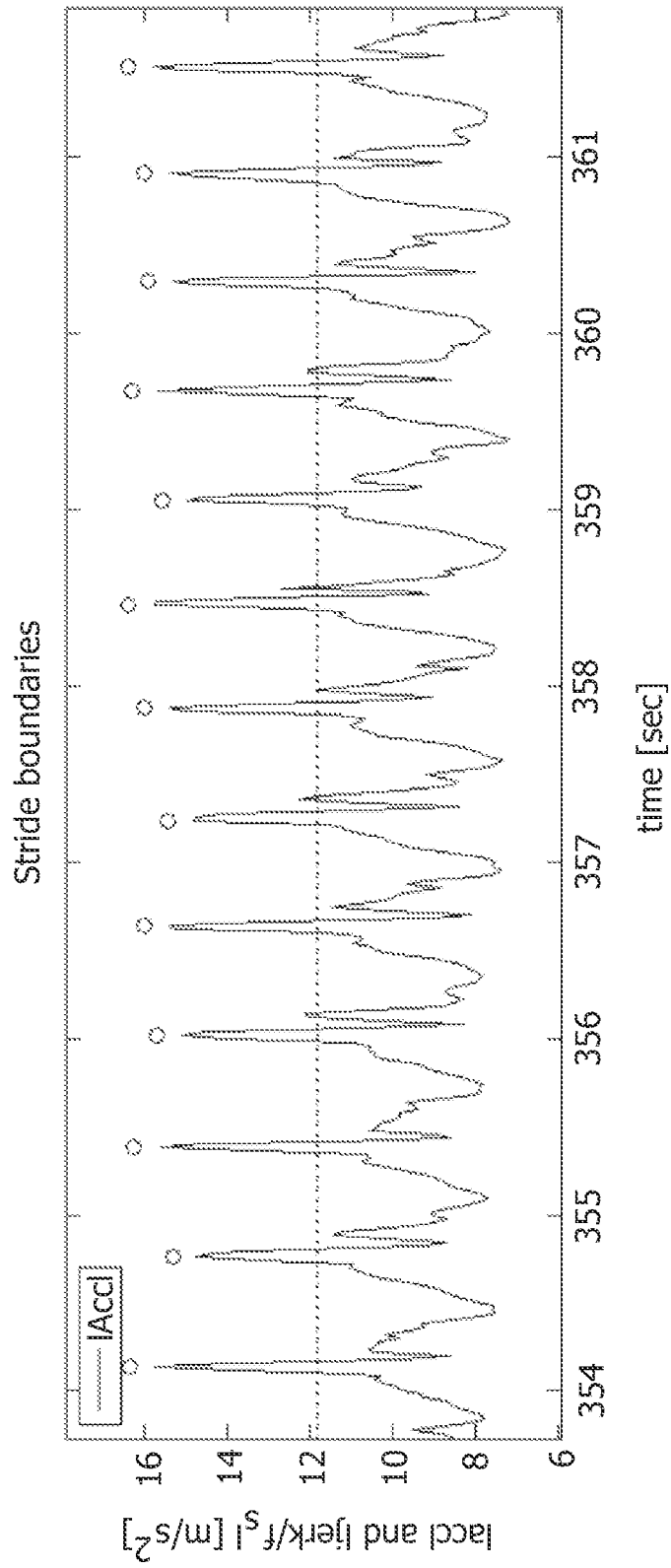


FIG. 4

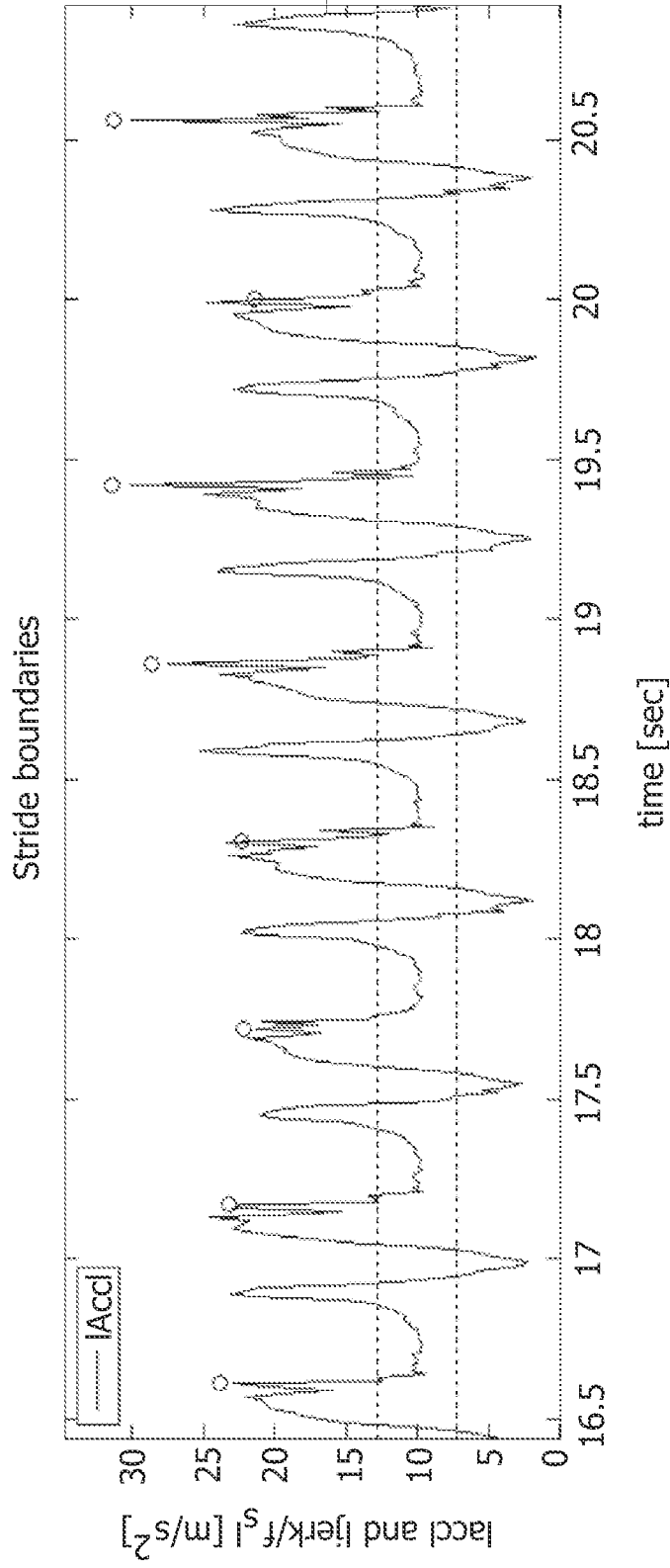


FIG. 5

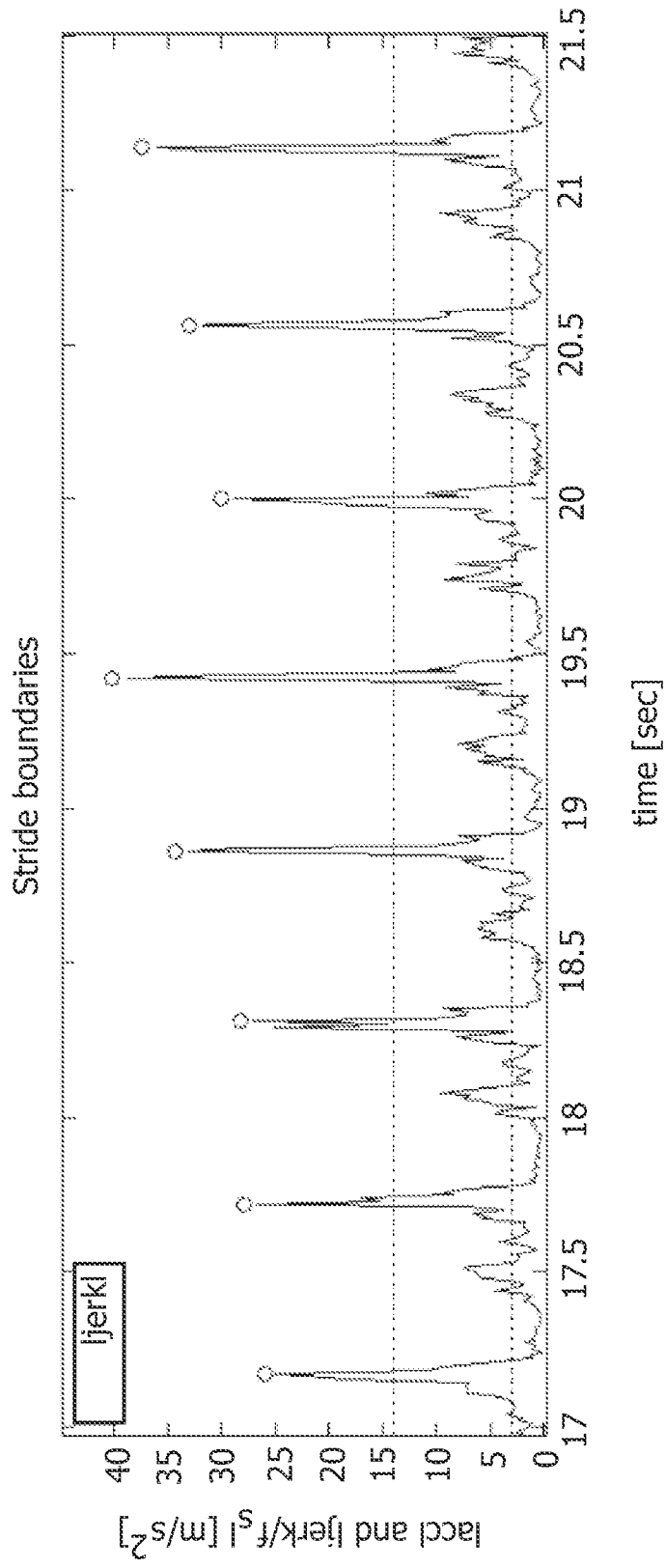


FIG. 6

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	预防跌倒		
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摘要(译)

提供了一种确定用户的跌倒风险的方法，该方法包括收集用户的运动的测量值，从测量值估计与用户的步态相关的参数的值，以及确定用户的跌倒风险。用户来自估计值与用户的运动所确定的参数的正常值的比较，其中用户的正常跌倒风险。

