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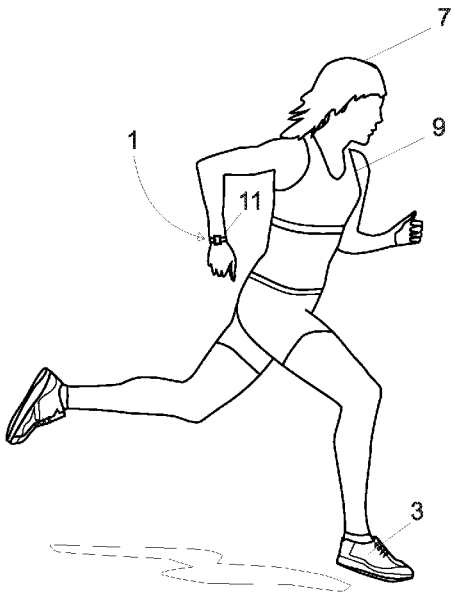


Fig. 4

(57) Abstract: A method for determining biomechanical parameters of the stride of a runner, using an accelerometer device on the wrist, on the upper arm, on the head or on the shoe, comprising the steps of measuring an initial sequence of acceleration data in at least the vertical direction using said accelerometer device; identifying in said initial sequence of acceleration data at least one frequency component caused by relative motion of the accelerometer device relative to the runner center of masse; attenuating said frequency component, so as to determine a modified sequence of acceleration data; determining said biomechanical parameters from said modified sequence of acceleration data.

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A method and device for retrieving biomechanical parameters of a stride

Field of the invention

[0001] The present invention relates to a method and to an accelerometer device provided with an accelerometer for retrieving biomechanical parameters of a stride.

Description of related art

[0001] The results of a runner depend essentially on cardiovascular endurance qualities and on the mechanical efficiency of the stride. Many devices and tests are known in the state of the art for measuring progress in terms of cardiovascular performance. For example, many runners train with a heart rate monitor that shows them their heart rate at any time, whilst different tests enable for example the maximum oxygen volume taken from the lungs and used by the muscles per time unit ($V0_2max$) to be measured.

[0002] The present invention relates more precisely to methods and devices for measuring the biomechanical efficiency of the stride. By improving the efficiency of each stride, the runner is able to run faster or longer with a given quantity of energy. It is however difficult, even for a runner accompanied by an experienced coach, to objectively measure the efficiency of his/her stride and improve it without resorting to measuring devices. In particular, there is a need for a method and device that are simple, portable, self-sufficient and capable of supplying, in real time and immediately after the run, parameters that are useful for analyzing the stride.

[0003] Wristwatches are also known that are provided with an inertial sensor. One example is described in EP1862765. The wrists of a runner, however, follow a very different trajectory from that of the athlete's center of mass and even briefly returns backward at each step. Such devices are

possibly useful for approximately evaluating the distance travelled or the number of calories expended during a running session, but are however incapable of analyzing the stride accurately.

[0004] When worn at the wrist, the motion of the accelerometer device includes both the motion of the runner's center of mass, plus all other motions resulting from the runner's joints and musculo-skeletal deformation. Typically, these extra motions include the movement of the arm (including lower arm and upper arm movements, resulting from the elbow and shoulder joints), the flexion, extension and compression along the length of the spine, as well as the motion around the scapula (shoulder blade) and clavicle (collar bone). Studying those extra motions might be interesting, but does not provide much information on the efficiency with which a runner displaces his center of mass.

[0005] Different companies also suggest placing an accelerometer in or on the shoe. One example is described in WO09094746. This location enables the trajectory of one of the two feet to be followed very closely. It is however far removed from the runner's center of gravity and therefore does not make it possible to detect for example whether the runner's torso oscillates or sways unsuitably. Furthermore, this sensor ignores what the other foot is doing and does not allow for example the runner's flight time duration at each stride to be measured. It also does not allow the behavior of the center of gravity to be analyzed and does not therefore allow an accurate analysis of the stride.

[0006] EP1897598 describes a training aid device for different sports. It uses an accelerometer on the ankle or knees. Again, these different locations are removed from the athlete's center of gravity and from his plane of symmetry, so that the measurements supplied are inaccurate or not relevant for analyzing the running style.

[0007] A much more precise evaluation of the runner's efficiency can be achieved with an accelerometer placed close to the center of gravity of the runner, for example on his chest, torso or back. Such an accelerometer

follows the displacement of the center of gravity of the runner and provide biomechanical parameters for analyzing the stride of a runner.

[0008] US20090018794 describes a device for measuring the progress of a moving person by means of an inertial sensor placed close to the center of gravity. The speed and the other parameters are determined on the basis of the maximum vertical acceleration or possibly of the minimum vertical acceleration by using a proportionality factor k. This factor k, which is not described in the document, depends however necessarily on the type of displacement, on the means of locomotion and on the running style; the computed results are thus equivocal or depend on unverifiable hypotheses about the factor k. The aim of this document is first and foremost to add indications obtained at each stride in order to display for example the travelled distance, the number of steps or the speed, but not to display parameters enabling the efficiency of each stride to be analyzed.

[0009] WO2011/157607, the contents of which is included by reference, is related to a method implementing an accelerometer for analyzing biomechanical parameters of the stride of a runner. The method uses a device with a triaxial accelerometer fastened on the torso of the runner, and a processor for calculating various parameters of the stride such as the lowering of the center of gravity, the stiffness, a regularity index, a fatigue level, and various other useful parameters.

[0010] Although much more accurate, accelerometer devices worn on the torso, chest or back are less comfortable since they usually require a belt or similar device to hold them. Therefore, they tend to be less popular than accelerometer devices worn on the wrist, on the head or on the shoe.

[0011] Therefore, there is a need for a method and device for determining biomechanical parameters of the stride of a runner with a high accuracy, using an accelerometer device on the wrist, on the head or on the shoe.

Brief summary of the invention

[0012] According to the invention, these aims are achieved by means of a method according to claim 1, and by means of a device according to claim 17.

[0013] In one aspect, the invention is also related to a method for determining biomechanical parameters of the stride of a runner, using an accelerometer device on one wrist, on one upper arm, on the head or on one shoe, comprising the steps of

measuring an initial sequence of acceleration data in at least the vertical direction using said accelerometer device;

extracting a sample window from said initial sequence of acceleration;

performing a FFT of said sample window, so as to compute a FFT signal;

inputting said FFT signal to a machine learning system, such as a neural network, in order to determine the current or predicted future cadence of the runner.

[0014] The expression "biomechanical parameters" designates parameters depending on trajectories, strength, power, speed or position of the musculo-skeletal system of the runner.

[0015] The expression "frequency component" could designate a specific frequency value, or a range of consecutive frequencies.

[0016] The attenuated frequency component might be constant over time, or variable over time. In one embodiment, the attenuated frequency component depends on the acceleration signal, for example on the running cadence.

[0017] The expression "attenuating a frequency component" includes for example filtering said frequency component out, or reducing the amplitude or energy of the portion of the acceleration signal within that

range. The attenuation might be constant within the range, or variable within the range. In one embodiment, the attenuation depends on the acceleration signal, for example on the running cadence.

[0018] The expression "accelerometer device" designates any device provided with an embedded accelerometer, including devices used for self-assessment during sport activities.

Brief description of the figures

[0001] Examples of embodiments of the invention are indicated in the description illustrated by the attached figures in which:

- Figure 1 illustrates an example of acceleration signal, in the frequency domain, measured with an accelerometer device close to the center of gravity.
- Figure 2 illustrates an example of acceleration signal, in the frequency domain, measured with an accelerometer device on the wrist.
- Figure 3 illustrates an example of frequency response diagram of a filter that converts the signal measured on the wrist into a nearly equivalent signal measured at the center of gravity.
- Fig. 4 illustrates a runner using one device according to one embodiment of the invention.
- Fig. 5 is a block-diagram of one device according to one embodiment of the invention.

Detailed Description of possible embodiments of the Invention

[0019] A device 1 according to the invention could be embedded in a wristwatch, in a smartphone, in a headset, in glasses etc. It generally

comprises a case and mounting means for fastening it to the wrist, to the upper arm, to the shoe, etc.

[0020] As illustrated on Figure 4, the device 1 might comprise and accelerometer 12 and a display 10.

[0021] The accelerometer 12 and the display 10 might be included into one single element, such as a sportwatch.

[0022] Alternatively, the device 1 comprises one first element containing the accelerometer 12 and worn on one wrist, one one shoe 3, on the head 7, on a T-shirt 9, etc , and a distinct second element, such as a smartwatch, a smartphone, a tablet, a computer, etc, that includes the display 10.

[0023] This display 10 makes it possible to display control menus, the memory status, the state of the battery, as well as numeric and qualitative parameters determined during and after the tests. Controls 13, such as buttons, a touch display, or other tactile elements, make it possible to navigate in the menus, to select options, to enter data and to select the results to be displayed.

[0024] The accelerometer 12 is preferably a triaxial accelerometer, for example an accelerometer based on a MEMS-type component, supplying distinct acceleration sequences along three normal axes. The orientation of the device and/or of the accelerometer relative to the runner is measured at standstill and thus enables the device-runner's frame of reference to be calibrated and transformed in order to measure accelerations in a frame of reference linked to the runner. In one variant embodiment, triaxial data of the accelerometer are projected and memorized along a single one of the axes or along two axes or along three axes. The accelerometer can have a privileged axis that affords a higher accuracy, resolution, range of measurement and/or frequency of acquisition than the other axes. This privileged axis has been advantageously oriented roughly vertically during a normal use, in order to improve the quality of the measurement in the vertical direction.

[0025] The device is preferably electrically self-sufficient and includes a battery 14, for example an accumulator charged through a USB connector or an appropriate charger. The battery 14 supplies all the components, including a microprocessor 11 or a microcontroller provided with a RAM and/or EEPROM memory. The microprocessor executes an EEPROM-memory program that can be updated via a USB or Bluetooth interface 15 for example, in order to control the display and to analyze the acceleration data supplied by the accelerometer. This program thus allows the computation means to be controlled in order to determine the biomechanical parameters of the stride on the basis of the sequences of acceleration data measured along one or several axes.

[0026] The device also includes a chronograph for measuring temporal durations Δt, as well as a loud-speaker or a buzzer, not represented, controlled by the microprocessor to generate alarms or sounds.

[0027] Figure 1 illustrates a sequence of acceleration data, in the frequency domain, measured with an accelerometer worn near the center of gravity, for example on the chest.

[0028] When worn at the wrist, the motion of the accelerometer device 1 includes both the motion of the runner's center of mass, plus all other motions resulting from the runner's joints and musculo-skeletal deformation. An example of acceleration data measured on the wrist is illustrated in the frequency domain on Figure 2.

[0029] Typically, these extra motions include the movement of the arm (including lower arm and upper arm movements resulting from the elbow and shoulder joints), the flexion, extension and compression along the length of the spine, as well as the motion around the scapula (shoulder blade) and clavicle (collar bone).

[0030] A large collection of algorithms is available for determining biomechanical runners of a runner from sequences of acceleration data measured at or close to his center of mass. Those algorithms can't be used

with sequences of acceleration data measured from the wrist (or shoe, of upper arm, or head), because the extra movements between the accelerometer device and the runner's center of mass would be detrimental.

[0031] Therefore, the following method is proposed to attenuate those extra movements and convert a sequence of acceleration measured at a wrist (or shoe, or upper arm, or head) into a modified sequence of acceleration at the runner's center of mass.

[0032] In a first step, at least one sequence of acceleration data is measured with the accelerometer device 1, such as a sportwatch, an accelerometer worn at the shoe, a smartphone worn on the upper arm, or an accelerometer embedded into a headset. The accelerometer is preferably worn remote from the center of mass of the runner, i.e., not on his chest, but rather on one limb or on his head.

[0033] The acceleration sequence could be measured with a triaxial accelerometer 12, and could correspond to one of the axis of the accelerometer. It is also possible to determine and use all three sequences of acceleration, corresponding to three axis. Alternatively, the three sequences are combined into one sequence, for example a sequence of acceleration along the vertical direction, and/or into three sequences, for example along the vertical, anteroposterior, and lateral directions relative to the runner. The sequences of acceleration might be filtered, for example using a low-pass or band filter, for example a software filter.

[0034] In a second step, a frequency corresponding to the cadency of the runner is determined. This frequency corresponds to the number of steps per second. This frequency might be determined by counting the number of steps during a predetermined period, using a step counting method known in the prior art. If multiple sequences of acceleration are determined, one of those sequences might be used for retrieving the cadence frequency. In one example, the acceleration along the vertical axis

might be used for easily detecting the choc each time one foot touches the ground, and thus to determine the cadence frequency.

[0035] In a third step, a sample window is extracted from at least one sequence of acceleration data, and a Fast Fourier Transform (FFT) is applied to this (those) sample(s). For each sample, this produces a digital signal in the frequency domain, as illustrated on Figure 2.

[0036] The most significant magnitude peak in each of those frequency signals is then extracted, and the device verifies that this peak corresponds to the previously determined cadence frequency. If the difference exceeds a threshold, the cadence frequency is recomputed.

[0037] Alternatively, the digital signal delivered by the FFT is input to a machine learning system, such as for example a neural network, in order to determine the cadence of the runner.

[0038] In another embodiment, the cadence frequency is determined only from the FFT(s), and there is no a priori determination of the cadence frequency with other means.

[0039] The cadence peak in the frequency signal has harmonics peaks. Peaks at different frequencies that the cadence peak and its harmonics denote the presence of other motion. Typically, the "arm swing" peak will be at half the frequency of the "cadence peak". The "arm swing" peak will also have harmonics, some of which will be superimposed on the "cadence" peak and its harmonics.

[0040] In the case of an accelerometer device 1 worn on the wrist 11, or on the upper arm, the extra motion is mainly related to "arm swing" at half the frequency of the cadence. The frequencies that correspond to the arm swing peak or its harmonics and do not overlay with the cadence peak are strongly attenuated with a filter in the frequency domain. The frequencies corresponding to the cadence peak and its harmonics are also attenuated, by an amount equivalent to the arm swing overlay.

[0041] The filter is thus a comb filter, preferably a digital comb filter, such as a software comb filter. It provides an important attenuation of frequencies in a plurality of frequency ranges, and a less important attenuation outside of those frequency ranges. An example of frequency response of the filter is shown on Figure 3.

[0042] The attenuation factor in each range (for each harmonic) is preferably determined in advance, and might be user-independent, although user dependent attenuation might be considered.

[0043] The comb filter determined during those steps is then used for subsequently filtering the continuous acceleration data sequences delivered by the accelerometer device. This generates one acceleration data signal, or a plurality of data acceleration signals along different directions, equivalent to the one that would be measured at the center of mass of the runner.

[0044] The attenuated frequencies are adapted during a run, for example periodically, and / or when the cadence frequency is modified (i.e. when the runner accelerates or decelerates), and/or in reaction to other triggers.

[0045] Given the center of mass signal(s), biomechanical running parameters are then computed using known methods, for example using the methods described in WO2011/157607.

[0046] The method can be implemented with minimal computing power requirement to run in real time on a processor embedded in the accelerometer device, for example in a wristwatch. This processor, along with the accelerometer embedded in the same wearable device, carry out all the above described steps.

[0047] Alternatively, the sequence of acceleration data might be transferred to a remote device, such as a smartwatch, a smartphone, a computer, a server, etc, that will perform the computations remotely.

[0048] The determination of extra motion performed with this method might be used to extract new biomechanical parameters, for example, relating to the arm movement in running.

[0049] The same method could be applied to an accelerometer device worn on the upper arm, for example a mobile phone held in a mobile phone holder on the upper arm. The only difference is that the extra motions do not include movement resulting from the elbow joint.

[0050] The same principle applies for a sensor worn on the head, typically using a headphone with embedded accelerometer or smart glasses. In this case, the extra motions do not include any motion from the shoulder or elbow joints, and instead includes movements from the neck joint. Head movements are usually low frequency signals, so filtering anything below the cadence peak would result in filtering out most of the head movement.

Claims

1. A method for determining biomechanical parameters of the stride of a runner, using an accelerometer device (1) on one wrist, on one upper arm, on the head (7) or on one shoe (3), comprising the steps of

measuring an initial sequence of acceleration data in at least the vertical direction using said accelerometer device;

identifying in said initial sequence of acceleration data at least one frequency component caused by relative motion of the accelerometer device (1) relative to the runner center of masse;

attenuating said frequency component, so as to determine a modified sequence of acceleration data;

determining said biomechanical parameters from said modified sequence of acceleration data.

2. The method of claim 1, wherein said step of identifying comprises:

extracting the cadence directly from said initial sequence of acceleration data;

using said cadence for determining said frequency component.

3. The method of one of the claims 1 or 2, wherein said step of identifying further comprises:

extracting a sample window from said initial sequence of acceleration;

performing a FFT of said sample window;

determining the most significant frequency peak from the transformed signal.

4. The method of claims 2 and 3, further comprising:

verifying that the cadence determined directly from said initial sequence of acceleration data corresponds to the frequency peak.

5. The method of one of the claims 2 to 4, wherein said step of identifying further comprises retrieving at least one harmonic peak from said cadence and/or from said most significant peak,

and wherein said step of attenuating comprises attenuating said harmonic peak.

6. The method of one of the claims 2 to 5, wherein said step of attenuating comprises attenuating frequencies at half the frequency of the cadence peak.

7. The method of one of the claims 2 to 6, wherein said step of attenuating comprises attenuating frequencies at some harmonics of the cadence peak.

8. The method of one of the claims 2 to 7, wherein said step of attenuating comprises attenuating the cadence peak by a first attenuation factor, and applying a greater attenuation to harmonics corresponding to the arm swing peak.

9. The method of one of the claims 5 to 8, wherein frequencies between two attenuated harmonics are less attenuated than said harmonics.

10. The method of one of the claims 1 or 2, further comprising:

extracting a sample window from said initial sequence of acceleration;

performing a FFT of said sample window, so as to compute a FFT signal;

inputting said FFT signal to a machine learning system, such as for example a neural network, in order to determine the cadence of the runner.

11. The method of one of the claims 1 to 10, performed in a wristwatch.

12. The method of one of the claims 1 to 10, wherein said step of measuring is performed in a wristwatch, while said steps of identifying, attenuating and determining are performed in a smartphone or in a computer.

13. The method of one of the claims 1 to 12, wherein said biomechanical components include at least one among:
flight time, contact time, lowering, elevation, undulation, asymmetry, regularity, reactivity, stiffness, take of angle, and/or landing angle.

14. The method of one of the claims 1 to 13, further comprising a step of using said at least one frequency component caused by relative motion of the accelerometer device relative to the runner center of masse, in order to determine the arm movement.

15. The method of one of the claims 1 to 14, said initial acceleration data being measured in a plurality of orthogonal directions, said attenuation being performed independently for each direction.

16. The method of claim 15, wherein the attenuated frequencies are the same for each direction.

17. An accelerometer device (1) for determining biomechanical parameters of the stride of a runner with a high accuracy, comprising:
means for fastening the device to one wrist (11), to one upper arm, to the head (7) or to one shoe (3);
an accelerometer (12) for measuring an initial sequence of acceleration data in at least the vertical direction;
a processing system (11) containing a processor and a memory containing a program code arranged for:
-identifying in said initial sequence of acceleration data at least one frequency component caused by relative motion of the accelerometer device relative to the runner center of masse;
-attenuating said frequency component, so as to determine a modified sequence of acceleration data;
-determining said biomechanical parameters from said modified sequence of acceleration data.

18. The accelerometer device of claim 17, further comprising:
a battery (14);
a display (10).

19. A tangible computer product containing program code for causing a processor to execute the method of one of the claims 1 to 16 when said code is executed.

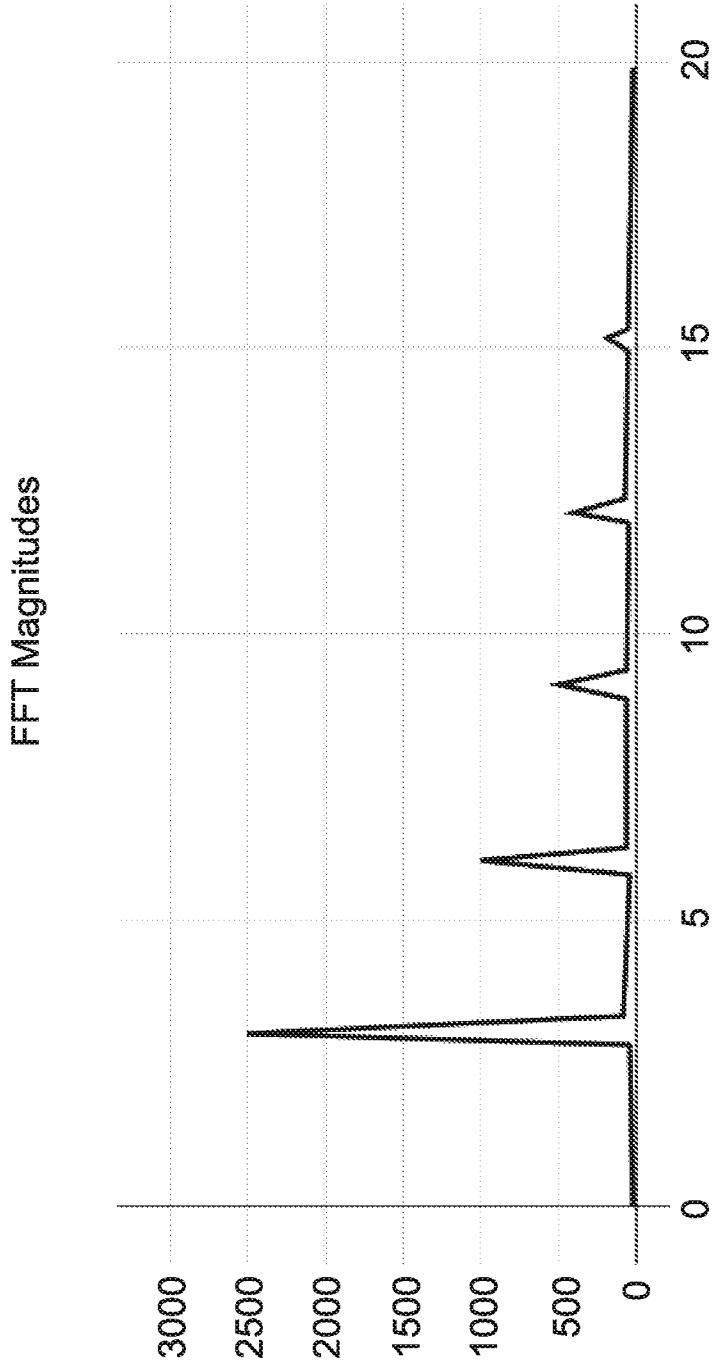


Fig. 1

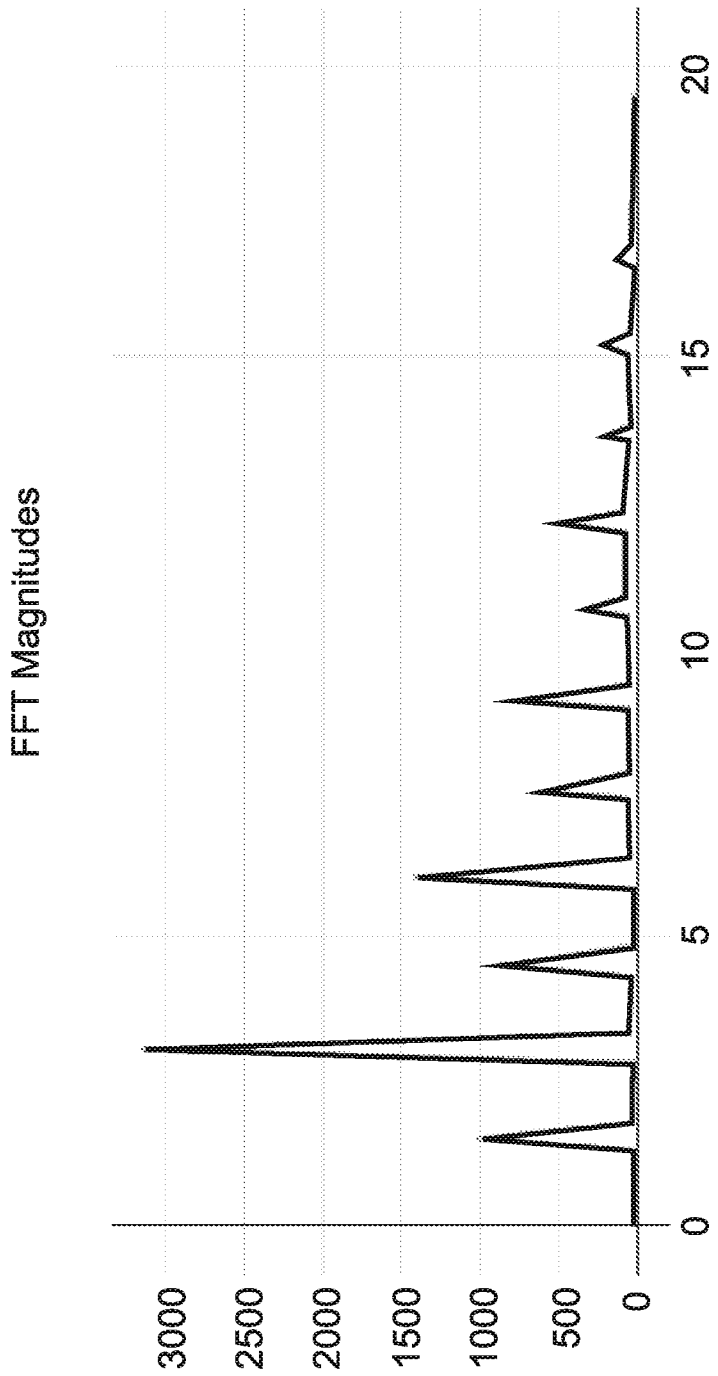


Fig. 2

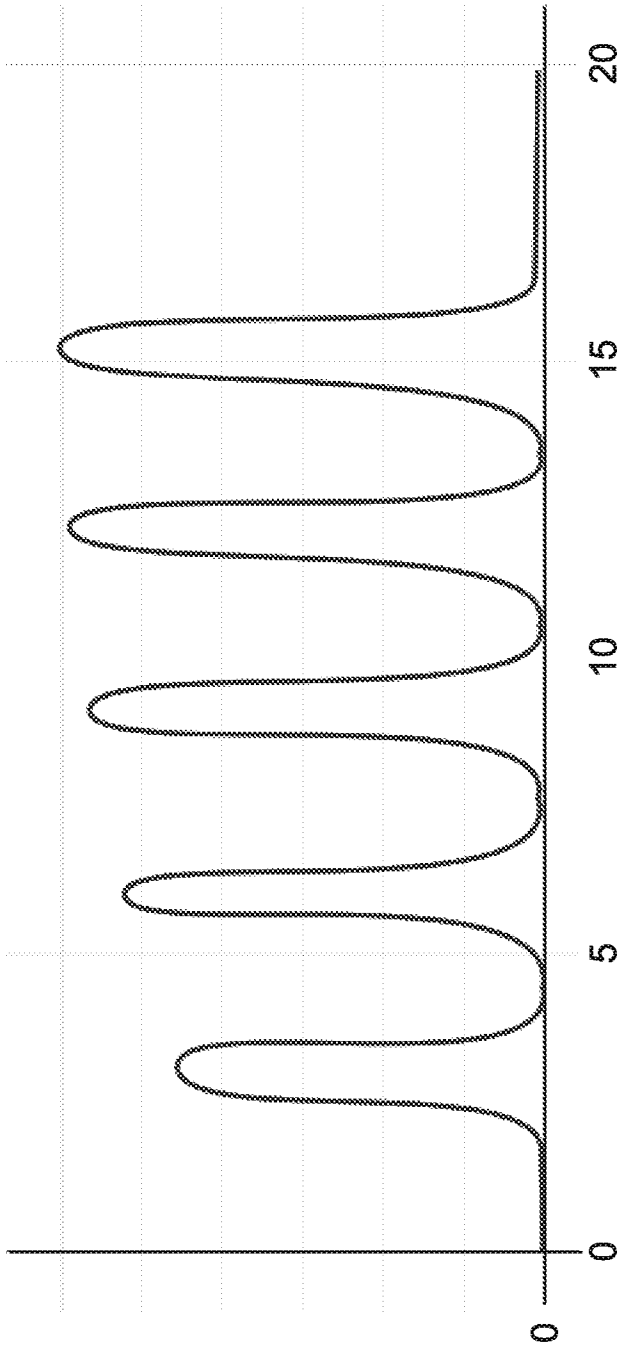
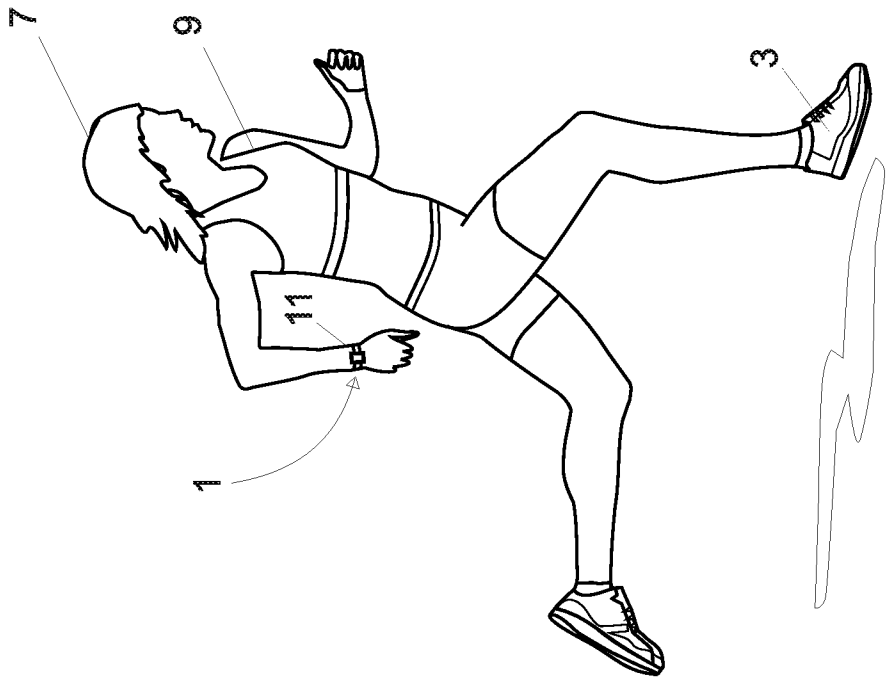


Fig. 3

Fig. 4



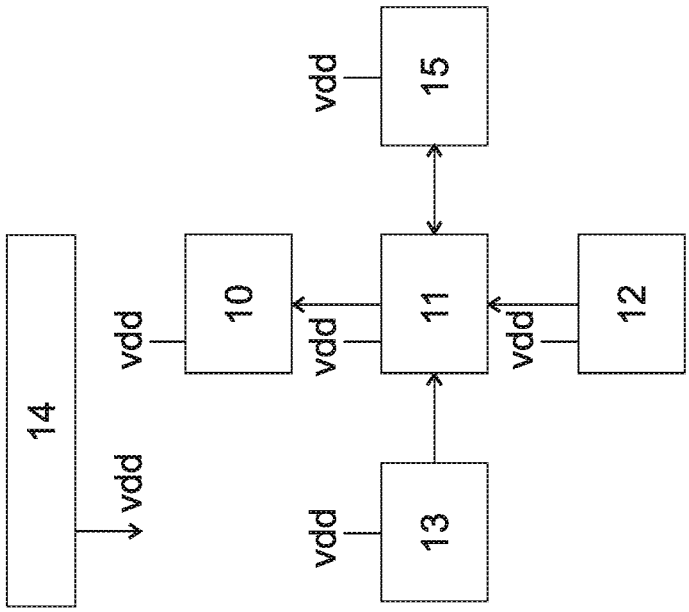


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/056598

A. CLASSIFICATION OF SUBJECT MATTER
INV. G09B19/00 G06K9/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G09B G06K G01C A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/094746 A1 (GARMIN LTD; KULACH CHRISTOPHER J [CA]; ROONEY JAMES K [CA]; MACDONALD) 6 August 2009 (2009-08-06) cited in the application paragraphs [0009], [0015] - [0021], [0049], [0050], [0056], [0073], [0074], [0077]	1-19
X	US 2013/191034 A1 (WEAST AARON B [US] ET AL) 25 July 2013 (2013-07-25) paragraphs [0061], [0091] - [0096] figures 7a,7b	1-19
A	US 2016/213975 A1 (FLACTION PATRICK [CH] ET AL) 28 July 2016 (2016-07-28) paragraphs [0046] - [0055]	1-19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 November 2018	22/11/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Gabriel, Christiaan

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2018/056598

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