Title: A DEVICE FOR DETECTING MOTION DATA OF A PERSON AND A METHOD FOR PROCESSING SAID DATA, PARTICULARLY FOR DETECTING THE SPEED OF SAID PERSON

Abstract: A device for detecting motion data of a person and a method for processing such data comprising a uni-directional instantaneous acceleration detector (16) associated with one of the two shoes (13s) worn by the person, a pair of ground contact detectors (14, 15) localized respectively in the region of the toe and the heel of the same shoe (13s), and an electronic processor unit (22) for processing signals emitted by these detectors (14, 15, 16). This unit includes a calculation module (27) adapted to calculate, by means of a predetermined algorithm, motion data of the person and other data derivable from it, and a display (28) for this calculated data. The average speed of a person equipped with this device is calculated, starting from average acceleration value (Aav), flight time (T) between contact with the ground of the toe of one shoe (13d) and contact with the ground of the heel of the other shoe (13s), and a ground contact time (ts) as the time which elapses between contact with the ground of the heel and contact with the ground of the toe of shoe (13s).
A device for detecting motion data of a person and a method for processing said data, particularly for detecting the speed of said person.

The present invention relates to a device for detecting motion data of a person and a method for processing said data, in particular to determine the speed of said person.

These days those who practice a sporting activity need to know in particular the speed reached during a run or a walk.

This requirement is felt not only by professional athletes, but also by those amateurs who always wish to improve their performance.

Currently there are available on the market devices integrated into special footwear provided with pressure sensors by which the intervals during which a foot is in contact with or out of contact with the ground are detected.

By suitably processing this information it is possible to establish the complete motion cycle of the athlete by knowing the number of ground contacts made alternately by the right and left foot.

At this point the speed is roughly evaluated by knowing the total distance travelled and the time taken to travel it.

However, this evaluation is the result of experimental and empirical functions and cannot be considered very reliable in that it does not detect the step effectively performed by the
athlete.

Normally, in fact, the "average" length of the running or walking step is calculated by means of a measurement taken on a predetermined run (or walk) during which the athlete must seek to maintain his pace constant.

Likewise there exist devices which use two or more accelerometers which co-operate with at least one rotational sensor with which the device can determine the speed reached by the user but, evidently, they are extremely complex and consequently expensive.

The main object of the present invention is that of making available a device for detecting motion data of a person, in particular for the purpose of evaluating the average speed reached, for example, during a sporting activity such as running, walking, climbing etc.

In relation to the main objective, a particular object of the present invention is that of providing a device for detecting motion data of a person, which guarantees a reliable and satisfactory evaluation of the speed of the person which can be made and continually updated during the performance of the running or walking action.

An important object of the present invention is that of providing a device for detecting the speed of running or walking which can be applied in a fixed or movable manner to the user’s footwear without this affecting or modifying the characteristics of the running or walking.
A further object of the present invention is that of making available a device for detecting motion data and a method for processing said data, in particular to determine a speed from said data, which does not demand to limit the possibilities of varying the person's pace.

Yet another object is that of making available a device for detecting motion data, which has a simple construction combined with an efficient function.

Not the least object of the present invention is that of making available a device for detecting motion data of a person which can be made at low cost.

The main objective, the stated objects and other objects which will become clearly apparent hereinafter, are achieved by means of a device for detecting motion data of a person, of the type defined in Claim 1, and a method of processing such data, of the type defined in Claim 12.

Further characteristics and advantages of the present invention will become clearer from the following detailed description of a preferred embodiment, illustrated indicatively, but without by this limiting its scope, in the attached drawings, in which:

Figure 1 is a schematic view of some components of a device for detecting motion data of a person according to the present invention;

Figure 2 is a general view of a person making use of the device for detecting motion data according to the invention;

Figure 3 is a schematic view of a component of the device illustrated in Figure 2;
Figure 4 is a graphic indication of the variation with time of the signal detected by the accelerometer sensor of the device when the user is running;

Figure 5 is a graphic indication of the variation with time of the signals detected by the pressure sensors of a first shoe during running; and

Figure 6 is a graphic indication of the variation with time of the signals detected by the pressure sensors of a second shoe during running.

With reference to the above-indicated drawings, a preferred embodiment of a device for detecting motion data of a person is generally indicated by the reference numeral 10 and is in part integrated in a first insole 11 and a second insole 12 which can be respectively fitted to first and second, left and right shoe 13s and 13d, for example of sports type, which are to be worn by the said person.

The following description will make reference to an application to sports footwear; it is to be noted, however, that this application is not intended to be limitative on the application of the invention but in particular, it lends itself to being applied also to normal footwear, or to special working footwear for work or for patients affected by illness such that they could find monitoring of the motor activity useful.

Integrated into the said first insole 11 are a first pressure sensor 14 disposed in correspondence with the front or toe end, a second pressure sensor 15 disposed in the heel region, and an accelerometer sensor 16 positioned in the mid-foot region.
The first and second pressure sensors 14 and 15 are preferably formed from a film of polymer the resistance of which reduces when the force applied perpendicularly to its surface increases.

The accelerometer sensor 16 in this case is of a type known per se and is composed of a micro mass of silicon suspended by a certain number of spokes anchored to a frame also of silicon. Electric resistors are fitted to the spokes, which modify their resistance value when, by the effect of an acceleration, the suspended micro mass varies the length of some of the said spokes which support it.

In other equivalent constructional configurations the accelerometer 16 could be of different type as long as it is provided with suitable characteristics.

In a manner equivalent to the first insole 11, the second insole 12 has a third pressure sensor 17 (in the region of the toe end) and a fourth pressure sensor 18 (in the heel region) integrated therein.

In the first insole 11 there is, moreover, integrated a power supply unit 19 of type known per se comprising a rechargeable battery not shown for simplicity in the drawings. In a constructional variant the power supply unit 19 recharges itself by using the movement of the feet in the manner of a device known per se in common use.

Each insole 11 and 12 is further provided with an interface unit 20 and connections 20c which connect each interface unit
20 with the pressure sensors 14, 15, 17, 18 and with the accelerometer sensor 16.

The structural configuration of each of the pressure sensors 14, 15, 17 and 18 integrated in the two insoles 11 and 12 is of a type substantially insensitive to vibrations and noise and, consequently, the relating interface units 20 are thus very simplified with respect, for example, to that which would have to be provided for detection with piezo-electric polymer pressure sensors.

In this configuration each interface unit 20 is connected to a transmission unit 21 also integrated in the corresponding first or second insole 11 and 12.

In this way the interface unit 20 receives signals provided by the sensors 14, 15, 16 or by the sensors 17 and 18 of the first and second insoles 11 and 12, and, thanks to the transmission unit 21, provides an analogue output signal to an electronic processor unit 22. The electronic processor unit 22 is, in this constructional arrangement, integrated in a watch device 23 secured by a wrist strap to the user.

The processor unit 22 comprises a receiver unit 24 an analogue-to-digital converter 25, a power supply unit 26, a microprocessor 27, a display 28 for displaying data, a clock 29, a memory 30 and selection keys 31.

It receives the analogue signals from the transmission units 21 of the interface units 20 and, after having converted them into digital signals, performs a calculation algorithm for
calculating the average speed reached by the person and renders data on such speed available by means of the display 28 at intervals determined by the athlete himself, for example by means of the keys 31.

It is also possible, in an alternative embodiment, to arrange for the analogue-to-digital converter 25 to be associated with the interface unit 20 of the insole so that it transmits digital signals to the processor unit 22. Again, the entire processor unit could be integrated in one of the two insoles, with the exception of the display 28, which is still maintained on the user's wrist.

The calculation algorithm for calculating the speed is based on the evaluation of the acceleration achieved by a foot of the person from the instant of activation of the sensor in the region the toe of a shoe (for example the right shoe 13d to which the second insole 12 is associated) up to the instant of activation of the sensor in the region of the heel of the other foot (for example the left shoe 13s, which is associated with the first insole 11 including the accelerometer sensor 16).

In Figure 4 there is shown the signal, indicated 33, detected by the accelerometer sensor 16 during the run of the person.

Numerous experimental tests have demonstrated in particular that only the accelerations detected by the signal 33 in the phase when both feet are in flight (which interval is indicated A in Figure 4) can be considered useful for the purpose of the determination of the speed.
To this end it is necessary to take into consideration the instantaneous acceleration, represented by the signal 33, lying between the moment (B) when the right shoe 13d which is not provided with the accelerometric sensor 16 leaves the ground (shown by the signal indicated with the numeral 36 detected by the third pressure sensor 17 positioned close to the toe of the second insole 12) and the moment (C) of contact with the ground by the heel of the left shoe 13s with the accelerometric sensor 16 (represented by the signal indicated with the numeral 35 detected by the second sensor 15 positioned close to the heel of the first insole 11).

In particular it is easy to verify that at the moment (B) when the shoe which does not have the accelerometer 16 leaves the ground, the acceleration detected by the accelerometer 16 of the other shoe, represented by the signal 33, is at a minimum value.

Once the values of the instantaneous accelerations, indicated for convenience $a_1, a_2, \ldots, a_n$, have been detected during the time period T of flight determined by the successive activations of the third sensor 17 and the second sensor 15, the electronic processor unit 22 effects a smoothing of these by calculating:

$$a'_1 = a_1$$
$$a'_2 = (a_1 + a_2 + a_3)/3$$
$$a'_3 = (a_2 + a_3 + a_4)/3$$
$$\vdots$$
$$a'_n = a_n$$

or, more generally:

$$a'_1 = a_1$$
\[ a_i' = \frac{(a_{i-1} + a_i + a_{i+1})}{3} \quad 2 < i < n-1 \]
\[ a_n' = a_n \]

At this point the processor unit 22 calculates average acceleration \( A_m \) and, given that the flight time \( T \) is known, evaluates the value of the average velocity \( V_n \) relating to the flight phase.

Correspondingly, thanks to the detections performed by the first and second pressure sensors 14 and 15 of the first insole 11, the electronic processor unit 22 is able to evaluate the speed of translation on the ground \( V_s \).

In fact, since the distance between the first and second pressure sensor 14 and 15, indicated \( d \), is known as well as the time, indicated \( t_s \), which elapses between the activation of the second sensor 15 located close to the heel and the deactivation of the first sensor 14 located close to the toe, the speed of translation on the ground is determined as:

\[ V_s = \frac{d}{t_s} \]

Once the average speed \( V_n \) relating to the flight phase is known and the speed \( V_s \) of translation on the ground is known, the average speed \( V \) is calculated as the weighted average referred to time with the formula:

\[ V = \left( \frac{(V_n \times T) + (V_s \times t_s)}{T + t_s} \right) \]

Finally, the average body speed is obtained as the arithmetic average of the speeds \( V \) calculated for \( n \) steps.

During the calculation of the average speed \( V \), the electronic
processor unit 22 does not take into account speeds the values of which have a percentage variation greater than or less than a predetermined limit value.

It is moreover possible to calculate the step rate of the person according to the expression:

\[ \text{rate} = 2 \times \frac{60}{t_p} \]

where \( t_p \) is the step time considered between two successive instants of contact of the heel of one of the said shoes.

The processor unit 22 performs a multiplicity of functions:

- it receives the analogue signals, by the receiver unit 24, arriving from the transmission units 21 of each interface unit 20 of the two insoles 11 and 12;
- it converts the said analogue signals into digital signals by means of the converter 25;
- it performs the timing functions thanks to the clock 29, detecting the times \( T, t_s, t_p \);
- it processes signals \( a_1, a_2, \ldots, a_n \) representing the instantaneous acceleration achieved by the athlete thanks to the microprocessor 27 according to the described algorithm;
- it displays the data on the display 28;
- it stores the data by means of the memory 30, and transfers the data to possible further remote processor units.

The electronic processor unit 22 may in fact be arranged to be interfaced by means of a suitable module not shown in the above listed figures, with an external PC, for example with an infrared interconnection, or with a pen provided with a corresponding receiving unit.
The device of the invention may also be arranged to receive a series of input data relating to the physical characteristics of its current user (for example body weight) to calculate, in dependence on the processed motion data, the calories consumption produced by the movement. It is moreover possible to display the posture of the user in the running or walking gait, following the constant monitoring of the contact with the ground by means of the described pressure sensors.

Preferably the transmission of the signals from the transmission units 21 of the first and second insole 11 and 12 to the electronic processor unit 22 utilises waves conveyed through the person’s body. With this type of transmission there is a propagation of electromagnetic waves which are conveyed through the skin of the human body, which functions as a wave guide, by means of electrodes connected to the body galvanically, or with capacitive couplings. In fact the outer layer of the skin of the human body is equivalent to an electrical conductor (thanks also to the sweat), the lucid layer composed of dead cells, is similar to a dielectric, whilst the dermis and the rest of the body, which is richly infused with blood is electrically equivalent to a conductor.

Such a transmission system works with very low power and voltages and, at the same time, with a relatively high frequency (about 100 KHz) and is absolutely harmless to the health and causes no annoyance or irritation.

The described insoles 11 and 12 may be applied to all types of footwear, not only those for running or walking.
The signals 33, 34, 35, 36 and 37 detected by the sensors 14, 15, 16, 17, 18 may be transmitted from the interface unit 20 (provided with a transmitter module) to an electronic processor unit 22 (provided with a corresponding receiver module) by means of signals radiated at radio frequency.

Given the signal 33 detected by the accelerometric sensor 16 relative to the instantaneous acceleration of the footwear provided with this sensor, it is in reality possible, in an equivalent constructional configuration, to utilise only the first insole 11 in association with a single shoe of a user.

In fact, the signals 36 and 37 provided by the third and fourth pressure sensor, respectfully indicated with the numerals 17 and 18, may conveniently be replaced by taking into consideration, for the calculation of the speed in the flight phase, only the instantaneous accelerations represented by the signal 33 lying between the minimum value (B) (in correspondence with which the shoe without the accelerometer sensor is off the ground) up to the instant (C) of contact with the ground of the heel of the shoe provided with the accelerometer sensor.

In this case however the same results are obtained with, in addition, the advantage of utilising a smaller number of components, therefore reducing the costs.

In other equivalent constructional arrangements it is possible to integrate the accelerometer sensor 16 and the first and second pressure sensor 14 and 15 directly in a shoe without having to use an insole.
It is evident how the present invention amply satisfies in practice the principle objective and all the stated objects.

In particular, an important advantage is obtained with the present invention due to the fact that it makes available a device for detecting motion data of a person and a method for processing such data able effectively to evaluate the speed.

It is important to remark, in particular, that the device described has a very simple constructional configuration and, whilst utilising a single accelerometer sensor without any rotational sensor, is able to determine the speed with a satisfactory precision.

An important advantage is achieved thanks to the fact that it makes available a device for detecting motion data of a person which has small dimensions and is of extremely low cost to produce.

Another important advantage is obtained with the present invention in consideration of the fact that it has made available a device for detecting motion data of a person which can be applied to the footwear thereof without affecting the way the movement is carried out.

Naturally, the principle of the invention remaining the same, the details of construction and embodiments can be widely varied with respect to what has been described and illustrated, without by this departing from the scope of the present invention as defined in the following claims.
CLAIMS

1. A device for detecting and processing motion data of a person, in particular for calculating the person's speed, characterised in that it comprises:

   unidirectional instantaneous acceleration detector means (16) associated with one of two shoes (13s) worn by the said person;

   ground contact detector means (14, 15), positioned in the region of the toe and the heel of the same shoe (13s) respectively; and

   an electronic processor unit (22) for processing signals emitted by the said acceleration detector means (16) and ground contact detector means (14, 15), the said unit including:

   a calculator module (27) adapted to calculate, by means of a predetermined algorithm, motion data of the person and other data derivable from it; and

   display means (28) for displaying this calculated data.

2. A device according to Claim 1, characterised in that the said calculator module (27) is arranged to calculate at least one of the following:

   the average speed of the person;
   the distance travelled by the person;
   the step rate of the person; and
   the calories expended by the person in the movement.

3. Device according to Claim 2, characterised in that the said processor unit (22) is arranged to receive input data relating to the physical characteristics of the person to calculate the calory consumption.
4. A device according to Claim 1, characterised in that the said unidirectional instantaneous acceleration detector means comprise a sensor (16) disposed in the mid-foot region.

5. A device according to Claim 1, characterised in that it includes an interface unit (20) coupled to the detector means (14, 16), including transmitter means (21) for sending signals emitted by the said detector means (14-16) to the electronic processor unit (22), the said processor unit being provided with corresponding signal receiver means (24).

6. A device according to Claim 5, characterised in that the transmitter means (21) and the receiver means (24) respectively comprise at least two electrodes connectable to the body of the said person, this latter being used as a wave guide for the propagation of the signals.

7. A device according to Claim 1, characterised in that the unidirectional instantaneous acceleration detector means (16), the ground contact detector means (14, 15) and the interface unit (20) are integrated in an insole (11) of the said footwear (13s).

8. A device according to Claim 1, characterised in that the said ground contact means (14, 15), comprise pressure sensors which are insensitive to vibrations, adapted to detect the flight phase and ground contact of the feet of the said person.

9. A device according to Claim 1, characterised in that it includes second ground contact detector means (17, 18) adjacent to the toe and the heel respectively of the shoe (13d) which
does not have the unidirectional instantaneous acceleration detector means.

10. A device according to Claim 9, characterised in that it includes a second interface unit (20) coupled to the said second detector means (17, 18), including second transmitter means (21) for transmitting the signals emitted from the said second detector means (17, 18) to the electronic processor unit (22).

11. A device according to Claim 10, characterised in that the second transmitter means (21) comprise at least two electrodes which can be coupled to the body of the said person, this latter being used as a wave guide for the propagation of signals.

12. A method for calculating the average speed of a person equipped with a device according to any preceding claim, comprising the step of:
   detecting a discrete succession of values of the instantaneous unidirectional accelerations of a first shoe (13s) worn by the person during the movement;
   from the said succession extracting the values lying between a minimum acceleration value corresponding to the instant (B) of separation from the ground of a second shoe (13d) and a nil acceleration value corresponding to the instant (C) of contact with the ground of the first shoe (13s), the said extracted values being indicated (a₁, a₂, ..., aₙ);
   effecting a smoothing of the said instantaneous acceleration values calculating a set of intermediate values (a₁', a₂', ..., aₙ') according to the equations:
\[ a_1' = a_1 \]
\[ a_i' = (a_{i-1} + a_i + a_{i+1})/3 \quad 2 < i < n-1 \]
\[ a_n' = a_n \]

calculating an average acceleration value \((A_n)\) starting from the said average values \(a_1', a_2', \ldots, a_n'\);

calculating the flight time \((T)\) as the time which elapses between the contact with the ground of the toe of one of the said shoes \((13d)\) and the contact with the ground of the heel of the other shoe \((13s)\) of the said person;

calculating an average speed value \((V_n)\) during the flight phase according to the relation:
\[ V_n = A_n \times T \]
calculating the ground contact time \((t_s)\) as the time which elapses between the contact with the ground of the heel and the contact with the ground of the toe of one of the said shoes \((13s)\);

calculating the ground translation speed \((V_s)\) according to the relation:
\[ V_s = d/t_s \]
where \(d\) is the distance between the ground contact detector means \((14)\) localized close to the toe of one of the said shoes \((13s)\) and the ground contact detector means \((15)\) localized close to the heel of the same shoe \((13s)\); and

calculating an average speed value \((V)\) according to the relation:
\[ V = [(V_s \times T) + (V_s \times t_s)] / (T + t_s). \]

13. A method according to Claim 12, further comprising the steps of:

calculating the time for one step \((t_p)\) as the time interval which elapses between two successive contacts with the
ground of the heel of one of the said shoes (13s) of the person; and

calculating the step rate of the person according to the relation:

\[ \text{rate} = 2 \times \left(\frac{60}{t_p}\right). \]
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

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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)

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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 practical, search terms used).

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Further documents are listed in the continuation of box C. Patent family members are listed in annex.

**Date of the actual completion of the international search**

| 20 June 2000 |

**Date of mailing of the international search report**

| 10/07/2000 |

**Name and mailing address of the ISA**

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3015

**Authorized officer**

Pflugfelder, G
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