(51) International Patent Classification:
A43B 3/00 (2006.01)

(21) International Application Number:
PCT/HU2014/00018

(22) International Filing Date:
4 December 2014 (04.12.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
P1400077 14 February 2014 (14.02.2014) HU

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Declarations under Rule 4.17:
— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(IH))

Published:
— with international search report (Art. 21(3))

(54) Title: MOTION ANALYSER DEVICE Equipped WITH TRI-AXIAL ACCELEROMETER, AND A METHOD FOR ITS APPLICATION

(57) Abstract: The subject matter of our invention is a motion analysing device that is made up of a shoe unit (72) equipped with at least one tri-axial accelerometer or at least one tri-axial radial angle meter that can be fastened in or on a shoe, and a central unit (71) that performs data transmission (73) with it. Another subject matter of our invention is a method for the application of the motion analysing device equipped with tri-axial accelerometer. A characteristic feature of our invention is that it has an arithmetic unit (51, 59) that is suitable for processing rotation and acceleration data and for computing the angle of incline (14) between the direction of motion (12) and the longitudinal axis (11) of the shoe; the central unit (71) contains a central battery (55), a central transceiver (56) and a central processing unit (58); the shoe unit (72) is equipped with battery (54) and a transceiver unit (53).
Motion analyser device equipped with tri-axial accelerometer, and a method for its application

The subject matter of our invention is a motion analysing device composed of at least one shoe-unit equipped with a tri-axial accelerometer, which is apt for being installed in or on a shoe, and a central unit performing data transmission with it. Our invention also explores the method for the application of a motion analyser equipped with tri-axial accelerometer.

Microchip accelerometers are devices used customarily for measuring directions and changes in directions, most widely in vehicles where they aid navigation or form a component of the safety accessories. An example for that is described in international patent document no. WO2013049819 outlining a solution where the position of a vehicle is determined with accelerometer. Vertical direction is obtained from gravity, whilst vertical movement and vehicle heading is computed by an algorithm from the vehicle's motion.

An invention described in US patent document no. US7921716 B2 uses accelerometer for measuring daily activities of an individual. In the course of walking or running, an accelerometer measures the angle of leaning, also, it is able to determine the acceleration vector of the foot and simultaneously other vector parameters, such as that of force. This solution is not suitable for determining the momentary direction of the foot or changes thereof as one moves.

Korean patent application no. KR20130013935 describes a system for analysing walks, which uses an accelerometer for measuring lengthwise and sidewise rolls of the foot in the course of walking. This analysis states whether or not a gait is normal. Neither this system takes into consideration the lengthwise orientation of the foot. The most careful manufacturing process notwithstanding, it may happen that directions determined by accelerometers will not accurately be aligned with the directions marked on the casing when assembled, therefore they should be calibrated. A device described for instance in patent disclosure no. US20100192662 A1 is suitable for calibrating accelerometers. This device can calibrate misalignment of axes of accelerometers with 1, 2 or 3 axes. When one's foot is in motion, the measure of the angle between the accelerometer and the casing does not really matter, what matters is that the direction of movement could be determined at least 10-times within 0.1-0.2 seconds.

There are countless methods for monitoring and analysing running or walking motion of athletes. Today more and more sophisticated techniques serve science. A patent registered in Hungary under register no. 229117 and case no. P0900341 measures forces that arise between the sole and the
ground on the contact surface. While one's foot rolls, the force measuring sensors installed on the sole continuously measure forces, however, forces could be measured precisely only if the direction of the shoe is aligned with the orientation. Human motion is rarely perfect i.e. foot is not heading forward in every moment, thus for the improved accuracy of measuring the determination of the momentary heading of the foot is necessary.

For instance, a device described in a US publication document no. US20120143514 A1 is suitable for sensing and processing subtle human motions. Unfortunately this tool is only suitable to identify the position of the parts of the body and does not enable measuring the angle of incline of either the foot or any other parts of the body.

A solution described in a US patent no. US5689099 measures the distance covered by a runner from the maximum forward and backward angular displacement of the leg relative to the trunk, and from the distance between sensors borne on the legs and on the hip. This solution does not measure the angle between the feet and the orientation.

Several precise and less precise methods are known for measuring angle of rotation. One of these methods is described in patent application no. US20130030756 Al. This invention measures the rotation of a device around a centre with known coordinates. The motion of the rotating body is measured by stationary devices fixed at points also with known coordinates. Such types of radial angle meters are not suitable for measuring the angle of incline of a foot, because it needs a mobile device instead of a stationary one.

Another procedure relying on external references could be GPS that at the present technology level is not precise enough to investigate a foot motion of some millimetres.

International application no. W09858236 A1 describes an invention that is suitable for measuring distances travelled, speed and height jumped. The method uses the path travelled by the airborne foot for calculations: the origin of a coordinate system is fixed to a moving object and the motion of this origin is then described, and the movement, speed and height are determined irrespective of the direction of the axes. In the course of taking measurements, the position of the foot contacting the ground is used only as a reference, and the moment of the footstrike is deemed to be the starting point for the measurement of the next motion cycle. This method is inapt for comparing the direction of the striking foot with the direction of movement.

The aim of our invention is the elimination of the deficiencies of the known methods, and the elaboration of a device and a method that are able to study motions precisely. To this end the angle
of incline between the directions of the foot and the movement should be measured, and this is our main aim. The longitudinal axis of the foot in most cases points inbound or outbound to the direction of movement and this could change from time to time. The angle of incline is impacted by the type of the movement and the intended motion. Therefore the angle of incline is not negligible data when the position of the foot is measured. The angle of incline is the angle measured between the direction of movement and the longitudinal axis of the foot or the shoe worn. Another aim is taking measurements in the course of any sort of sports (walking, running, tennis, etc.). A further aim is that the number of inclination angle data measured during a single step cycle would be sufficient for the accuracy of measuring.

Our inventive activity is based on the perception that motions could more accurately be studied and better understood if we were aware of the current inclination angle of the foot. For instance, if we would like to interpret the forces exerted on the sole when one is running, we should take into consideration the direction of the angle of incline. The same force exertion should be interpreted differently when the foot inclines outbound or inbound to the direction of the movement. The main task of our study is to measure the angle of incline between the direction of the movement and the longitudinal axis of the shoe with a method that during any step cycle produces inclination angle data sufficient for the accuracy of measuring. Measuring has two phases. Firstly we measure the direction of movement and afterwards we measure the angle between the foot and the direction of movement i.e. the angle of incline. One possible method for determining the direction of movement is based on the perception that when humans or animals walk or run, their legs move cyclically and when a cycle was finished, the vector that connects positions taken by a given foot will be the motion vector. In this case the direction of the motion vector should be deemed as the direction of movement. Our method determines the direction of movement for each foot. This perception encourages us to fix accelerometer to given points of the foot or the sole and so observe motions in our patentable method. A tri-axial accelerometer captures momentary acceleration values with a given periodicity. The leg itself is a three-dimensional curve where each point can be characterised by an acceleration value. Points of the curve are projected on the ground, which produces a motion vector that in the meantime is the direction of movement. The idea that accelerometers heading directions that deviate from the axis of the foot or the shoe by a predetermined angle can be installed in the shoe enables an expedient application wherein the angle of the direction of movement measured with an accelerometer corrected with the predetermined angle of that accelerometer will be the angle of incline of the foot travelling in the air. Another expedient method for the determination of the direction of movement is that an accelerometer is installed on the body,
reasonably at or close to the centre of gravity, and the movement of the object is so determined. A further expedient method for determining the direction of movement is the collation of the direction of the movement and the feet with an external reference. Such external reference can be the north magnetic pole or the rotation axis of Earth or signals emitted by devices installed at points with known coordinates. The second measuring phase is the determination of the inclination angle of the foot contacting the ground. In an expedient application, inclination angle is measured with radial angle meter. A reasonable method for measuring radial angle is the use of a gyroscope, another reasonable method is the use of one or several accelerometers, but there are other expedient methods such as those described in the section that explains measuring of the direction of movement, or with any other technical device that do not interfere with the substance of the method, either independently or in combination with any of the above. If the inclination angles of the left and the right shoes would be collated with the movement of the body's centre of gravity, a reasonable solution would be the use of positioning methods applied in navigation or the use of external references.

In view of the objective set, the subject matter of our invention will in general be realised according to Claim no. 1. The most generalised form of the application procedure is explained in Claim no. 6. Specific realisation methods are described in sub-claims.

In general, the device is made up of a shoe unit equipped with tri-axial accelerometer that can be installed in or on a shoe, and a central unit performing data transmission with it. A characteristic feature of our invention is that it has an arithmetic unit that is capable of processing rotation and acceleration data and calculating the angle between the movement direction and the longitudinal axis of the shoe; the central unit has a central battery, a central transceiver unit and a central processing unit; the shoe unit has a battery, a transceiver and a radial angle meter.

Another possible design is where in addition to the above the device is equipped with battery and transceiver.

In the customary use of our invention, a radial angle meter installed in the shoe unit measures the rotation angle of the longitudinal axis of the foot contacting the ground and exerting forces whilst in contact with the ground, and an accelerometer installed also in the shoe unit at predetermined regular times records the characteristics of the path of the foot travelling in the air, and then the central arithmetic unit processes these characteristic data and determines the inclination angle between the longitudinal axis of the foot and the direction of movement.
Hereinafter the invention will in more detail be explained along a possible design on the basis of drawings.

**Drawings attached:**

Fig. 1 lateral view of a human body with units installed

Fig. 2 bottom view of a sole

Fig. 3 interpretation of the motion vector from a series of connecting steps

Fig. 4 bottom view of a shoe sole with various sensors placed on it

Fig. 5 block diagram showing the logic relationships among the units

Fig. 6 a. lateral view of the path of a step

Fig. 6 b. top view of the path of a step

Fig. 1 is the lateral view of a human where the central unit 71 is fixed at the waist and the shoe unit 72 is fixed on the shoe; data transmission 73 is performed between the central unit 71 and the shoe unit 72.

Fig. 2 shows a sole for illustrating various directions. The longitudinal axis of a foot 11 is not necessarily aligned with the direction of movement 12. In most cases there is a lateral or medial angle between the longitudinal axis 11 and the direction of movement 12; moreover, the longitudinal axis 11 may from time to time rotate by Δα angle 13; e.g. it can deviate between heel strike and propulsion from toes. The angle between the direction of movement 12 and the longitudinal axis 11 of the foot is the inclination angle 14, this inclination angle 14 should be measured. The rotation of the longitudinal axis 11 pointing to the toe of the shoe is measured by rotation angle Δα 13. In the measuring process the direction of movement 12 and x-y plane 15 of the shoe is transformed to a plane by parallel shift in such manner that the vector of the direction of movement 12 would start from the origin of x-y plane 15.

The motion vector could be determined in several ways from among which three are shown on Fig. 3/A to C. On Fig. 3/A we can see the evolvement of human walk from a series of steps 21. The line connecting the positions of a given foot is the motion vector 22 that is measured separately for the left and the right foot. Fig. 3/B is an improved version of the foregoing where a mean 23 is calculated (averaged) from motion vectors 22 of the left and the right feet, which could be deemed
as the motion vector of the centre of mass. Fig. 3/C starts from the path of the centre of mass 24 of a human and can draw the direction of movement 25. It can be observed that at certain motion types each motion vector 22 of a given foot goes parallel or almost parallel with the dashed lines 26 drawn in between two successive peaks of a wavy line drawn for a given foot, which represents the movement of the centre of mass. This feature enables parallel transformation that can be used for calculation purposes.

Fig. 4 shows, as an example, the bottom view of a shoe that is equipped with force metering sensors, too, where electronic circuit 34 is indicated that is connected through wires 36 with the sensors 31, the accelerometer 33 and the radial angle meter 35. The accelerometer 33 and the radial angle meter 35 are installed separately in each shoe and operate independently of each other. For each sensor 31 a coordinate axis is defined a coordinate system defined by the axes 32 and the origin of each such coordinate system is the centre of the given sensor 31. The inclination angle is transformed into the coordinate system of the sensor that actually bears the load.

Fig. 5 illustrates expedient connections among electronic units. In the left and in the right shoes shoe units 72 are installed. In each shoe unit 72 an accelerometer 33, a gyroscope 35, an arithmetic unit 51, a data storage unit 52, a transceiver unit 53 and a battery 54 can be found, which collect and store data and perform the necessary mathematical operations. The main task of the central unit 71 is the harmonisation of the measurements taken by the two shoes and the storage and processing of data in one place. The central data storage unit 57, the central processing unit 58 and the central arithmetic unit 59 collect, store and process the data produced by both feet. Further components of the central unit 71 are the central battery unit 55 and the central transceiver 56.

Fig. 6 a and fig. 6 b show the lateral respectively the top views of the path 61 of a step 21. The device measures acceleration data at predetermined measuring points 65. If such predetermined measuring points 65 follow in sufficiently rapid succession, the path 61 could on the basis of the sampled data be deemed as continuous, and the result calculated by integrating the positions of these successive measuring moments 65 will be sufficiently accurate. The resultant of the direction vectors 64 between the starting point 62 and the ending point 63 delineates the motion vector 22. Single mathematical integration of the momentary acceleration values produces the momentary direction vector 64 of the foot-motion.

In the process of applying our invention, in order to achieve the desired results, a central unit 71 is placed on the body, for instance on the chest or on a belt near to the gravity centre of the body or at any suitable place. Such central unit 71 is already supplied with a central battery 55, a central
transceiver unit 56, a **central** data **storage** unit 57, a **central** **processing** unit 58 and a **central** arithmetic unit 59, furthermore - dependency upon the actual design - with other environment sensors, and auxiliary, easing and other units. Data produced by the accelerometer 33 and by the radial angle meter 35 and the data already processed are stored separately. A shoe unit 72 is installed in each shoe. The following devices are installed in each shoe unit 72: an accelerometer 33 used for measuring movement, a radial angle meter 35, a arithmetic unit 51, a data storage unit 52, and a transceiver unit 53. Accelerometer 33 and radial angle meter 35 are built separately in each shoe and are operated independently of each other. The central unit 71 is used for harmonising the measurements taken by the two shoes, for storing and processing data in one place. With the help of the central processing unit 58, the central arithmetic unit 59 and the central data storage unit 57, data measured on both feet are collected, stored and processed. By way of collating the directions of movement 12 of the two feet, calculation errors if any happening in the course of the determination of the direction of movement 12 are eliminated by averaging or by other mathematical-statistical methods. Measurements are taken by the accelerometer 33 when the foot travels in the air. The direction determined by a motion vector calculated from the path of the foot travelling in the air will be used as a reference for measuring the inclination of the foot. Acceleration data measured by the accelerometer 33 will be temporarily stored and then, through the transceiver unit 53 and the central transceiver unit 56 will be transmitted to the central processing unit 58, and this will be followed by calculations performed by the central arithmetic unit 59. Finally, the original or processed data will be stored in the central data storage unit 57 of the system. Reasonably the data transmission 73 is not continuous, its pace is controlled by the central processing unit 58. The central processing unit 58 alternately requests data measured by the left and right shoe units 72. Data so captured are processed by the central processing unit 58 in real time. This is the device where data are processed, and the data retrieved from both feet are collated and the accuracy of the direction of movement 12 is improved. When this device is operated, acceleration data are continuously, at successive predetermined measuring points 65 measured by the accelerometer 33. Data are transmitted to the electronic circuit 34 where they are captured in real time. The function that best matches the path of the movement of a foot can also be calculated from some known points. Single mathematical integration of the path of locomotion calculated from the momentary acceleration values at any given point produces the momentary direction vector 64 of the foot-speed; double integration results in the motion vector 22 between the starting point 62 and the ending point 63. If predetermined measuring points 65 follow in sufficiently rapid succession, the path 61 delineated by sampled data can be deemed to be continuous and the calculation of the path is unnecessary. Thus the integration of the positions of the successive predetermined measuring points 65 produces
sufficiently accurate result. Integration could be replaced by any other well-known approximation procedure (e.g. series expansion). A motion is a distance travelled by the airborne foot between the moments of propulsion and footstrike, which is characterised by its direction and length. The measurement of a motion could reasonably be started at the moment when the foot contacts the ground or the moment of propulsion, although a starting point could within this interval be selected anywhere, provided that the starting time and the end time will be at the same point of the motion or the sole. When the foot contacts the ground, accelerometer 33 will measure gravity, thus acceleration = 1g then x=y=z=0, which will be the initial result of integration. The initial value for each successive measurement will be given on the basis of the result of the preceding integration. A line can be drawn in between two measured positions, this line will be projected on x-y plane 15, and a i.e. the inclination angle 14 in any given point will be measured against such projection. This transformation, too, will be performed with the use of the electronic circuit 34 and the arithmetic unit 51. At the moment when the foot contacts the ground, a i.e. the inclination angle 14 will be calculated by the arithmetical unit. The inclination angle 14, i.e. a of the foot on the ground is not necessarily constant and could during the rolling phase slightly and continuously change; in between two successive measurements it will incline by Δα angle 13. This slight change is measured with radial angle meter 35. This is advantageous if several force meter sensors 31 are installed in one shoe and we should calibrate the results measured by all sensors in operation as they could be interpreted in the plane determined by the axes 32. In this configuration, sensors 31 are connected to the electronic circuit 34 with appropriately laid wires 36. The first measuring is taken in the moment when the foot has contacted the ground, then the rotation angle 13 of a given sensor i.e. Δα=0 thus the rotation angle and the angle of incline 14 (angle between the direction of movement 12 and the longitudinal axis 11 of the foot) are identical. From this moment the rotation angle is continuously measured. The second measuring computes the rotation angle by adding the rotation angle 13 stated by the second measuring to the angle of incline 14. Afterwards the input used in each successive measuring will be the output of the preceding measuring, which then will be corrected with the rotation angle 13: Δα = α1 + Δα1. The inclination angle 14 corrected with rotation angle Δα will be collated with the result of the measurement taken by the given sensor 31 at the corresponding moment. Measurements can be taken simultaneously by several sensors 31, which will be separately evaluated by electronic circuit 34, and afterwards resultant is calculated as a single coordinate.

The device presented herein has several advantages. One of these advantages is that in comparison with devices known so far, it improves the accuracy of motion studies, and another important
advantage is that measurements can be taken during any type of motions or sports. Precise measurements could be taken despite the fact that in most cases the longitudinal axis of the foot points outbound or inbound relative to the direction of movement, the directions of the two feet are not necessarily symmetric, or even they may during motion change from time to time, e.g. they can be different at heelstrike and at propulsion from the toes. Direction is impacted by the type of movement and dependently upon the intended motion it can change continuously. However, if the inclination angle is known, motion studies can be improved. This device assists in discovering sidewise swaying or vertical "bouncing" of a runner and/or specific features of a given type of movement when the directions of movement measured on the two feet are compared. Analysis of sufficient number of steps, use of known statistical methods and identification of the type of movement enable minimisation of calculation errors. For instance, direction of movement is measured separately on the right and the left foot, measured results are collated, or the errors that may occur during the measurement of the direction of movement on both feet are eliminated by way of averaging. Great advantages can be achieved when another solution is applied, namely that direction of movement is collated with an external reference direction whose coordinates are known. Such external references include the north magnetic pole, GPS, or another basis fixed at a known place. A transmitter signalling a reference direction, which during practicing is installed close to the tracks and fields could achieve this aim. An important advantage of our invention is that original and already processed data can be further processed by smart phone, computer or other info-communication mean. These means do not interfere with the substance of our invention but offer additional possibilities for data processing and displaying. Further advantage is that the units can be installed and measurements could be taken in several ways, which enable various solutions. The central unit can be placed in the shoe or on any part of the body, on the arm, waist or chest.

In addition to the examples described in the foregoing, our invention could within the scope of patent protection be manufactured in various designs and through various manufacturing procedures.
CLAIMS

1. A motion analysing device that is made up of a shoe-unit (72) apt for being installed in or on a shoe, which is equipped with at least one tri-axial accelerometer or with at least one tri-axial radial angle meter and a central unit (71) which perform data transmission (73) with each other, whereas it is equipped with an arithmetic unit (51, 59) suitable for processing rotation and acceleration data and for the calculation of the angle of incline (14) between the direction of movement (12) and the longitudinal axis (11) of a shoe; the central unit (71) is equipped with central battery' (55), central transceiver unit (56) and central processing unit (58); and the shoe unit (72) is equipped with battery (54), transceiver unit (53) and accelerometer and/or radial angle meter 35.

2. The device described in Claim 1, whereas the arithmetic unit is composed of the arithmetic unit (51) installed in the shoe unit (72) and/or the central arithmetic unit (59) installed in the central unit (71) and/or an external arithmetic unit.

3. The device described in Claims 1 and 2, whereas the central unit (71) that harmonises data captured by the shoe units (72) is equipped with a central data storage unit (57), and the shoe unit (72) is equipped with a data storage unit (52).

4. The device described in Claims 1 to 3, whereas sensors (31) apt for measuring environmental characteristics and other characteristics of a human body or motions are installed in the shoe unit (72).

5. The device described in Claims 1 to 4, whereas the central unit (71) and the shoe unit (72) are wirelessly connected to each other.

6. A method for the application of the motion study device described in Claim 1, whereas the radial angle meter (35) installed in the shoe unit (72) measures the rotation angle (13) of the longitudinal axis (11) of the foot that is contacting the ground and exerts forces whilst ground is contacted; and the accelerometer (33) also installed in the shoe unit (72) captures the characteristics of the path (61) of the foot travelling in the air, at predetermined measuring points (65); the central arithmetic unit (59) will on the basis of these characteristics determine the angle of incline (14) between the longitudinal axis (11) of a foot and the direction of movement (12).

7. The method described in Claims 5 and 6, whereas the data so collected will be stored in the central data storage unit (57) of the central unit (71) and in the data storage unit (52) of the shoe unit (72).
8. The method described in Claims 5 to 7, whereas the inclination angle (14) of the feet will be determined independently by electronic circuits (34) installed in or on the shoe, without the involvement of the central unit (71) serving for harmonising data measured on the two feet.

9. The method described in Claims 5 to 8, whereas measurements taken will be supplemented with other measures taken by direction sensitive sensors (31).
**A. CLASSIFICATION OF SUBJECT MATTER**

**INV. A43B3/00**

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)

A43B

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**

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<td>US 2009/235739 AI (MORRIS BAMBBERG STACY J [US] ET AL) 24 September 2009 (2009-09-24) paragraphs [0008], [0009], [0012], [0014], [0023], [0028], [0031]; claims 1, 17</td>
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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: 18 March 2015

Date of mailing of the international search report: 27/03/2015

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