



(51) International Patent Classification:
G06K 9/00 (2006.01) *A61B 5/11* (2006.01)

(21) International Application Number:
PCT/EP2019/067618

(22) International Filing Date:
01 July 2019 (01.07.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
102018000006950 05 July 2018 (05.07.2018) IT

(71) Applicants: **POLITECNICO DI MILANO** [IT/IT]; Piazza Leonardo da Vinci, 32, 20133 Milano (IT). **FONDAZIONE PER LA RICERCA SCIENTIFICA TERMALE** [IT/IT]; Via Po, 22, 00198 Roma (IT).

(72) Inventors: **PEDROCCHI, Alessandra Laura Giulia**; Via Papa Giovanni XXIII, 10, 20090 Segrate (Milano) (IT). **FERRANTE, Simona**; Via Ciceri Visconti, 14, 20137 Milano (IT). **BRAGHIN, Francesco**; Via Firenze, 12, 21100 Varese (IT). **GANDOLLA, Marta**; Via Calcinate, 7D, 21026 Gavirate (Varese) (IT). **COSTA, Andrea**; Via Napolini, 42, 29122 Piacenza (IT).

(74) Agent: **ZELIOLI, Giovanni**; BOTTI & FERRARI S.r.l., Via Cappellini, 11, 20124 Milano (IT).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

(54) Title: SYSTEM FOR DETECTION AND KINEMATIC MONITORING OF BODY MOVEMENTS IN WATER, AND RELATIVE METHOD

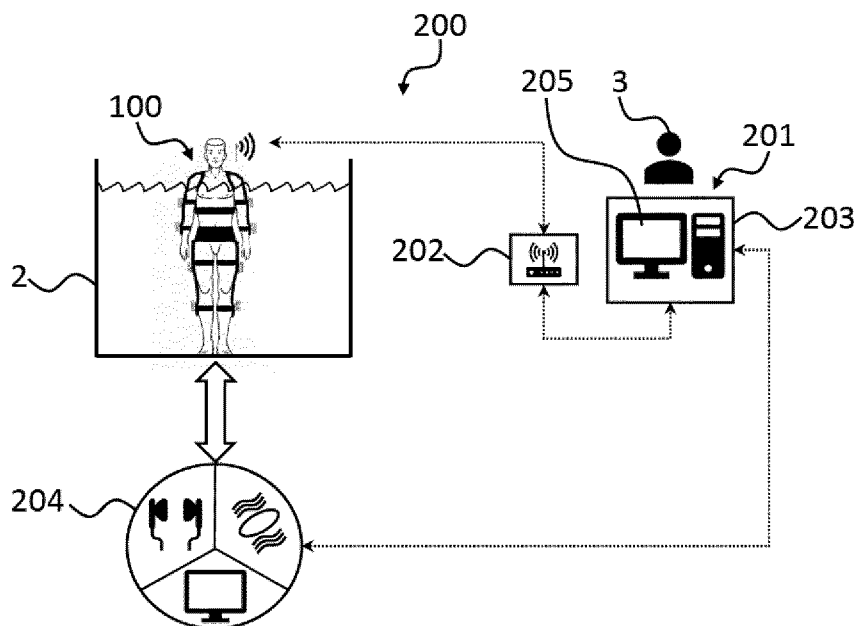


FIG. 2

(57) Abstract: The present invention relates to a system for detection and kinematic monitoring of body movements in water, comprising: a wearable device (100) for a user and adapted for use in water, comprising: at least two inertial measurement units (101) adapted to be associated with at least two body segments of said user respectively, said body segments defining at least one angle variable with a body movement between them, said at least two inertial measurement units (101) comprising sensors configured to detect kinematic values of said body movement and to convert them into measured data, and further comprising at least one master node (102) connected to said at least two inertial measurement units (101) to collect said measured data, said master node (102) being further configured for an online transmission of said measured data; a processing system (201) comprising: a receiver (202) configured for an online reception of said measured data, and further comprising a computer (203) operatively connected to said receiver (202) and configured to reconstruct said body movement of said user in real time starting from said measured data, and further configured to carry out a comparison between said reconstructed body movement and predefined kinematic parameters; a feedback system comprising: at least

OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

one feedback device (204) configured to receive information relating to said comparison and further configured to deliver at least one indication about said body movement at least to said user based on said information. The present invention further relates to a relative method for detection and kinematic monitoring of body movements in water.

- 1 -

Title: System for detection and kinematic monitoring of body movements in water, and relative method

DESCRIPTION

Technical field

- 5 The present invention relates to a system for detection and kinematic monitoring of body movements in water, and a relative method for detection and kinematic monitoring of body movements in water.

In general, the present invention finds application in the field of detection and monitoring of body movements or of relative movements of body
10 segments, also for training, sports, rehabilitation or diagnostic purposes.

Background art

In the context of thermal therapies, rehabilitative and sports therapies cover a wide range of sceneries for motor exercises that involve the body segments.

- 15 It is necessary to monitor the execution of these body movements in order to guarantee that they are executed correctly from the rehabilitative point of view or that they are executed efficiently from the point of view of sports.

There exist known solutions for detection and kinematic monitoring of
20 body movements based on a plurality of sensors associated with the body or with segments thereof.

Document US2005179202 (A1) relates to a system for tracking and assessment of movements in a multi-dimensional space that uses optical sensors. The solution known in US2005179202 (A1) is inefficient for use
25 in water, and further, it does not allow a detection with adequate precision for monitoring of a rehabilitative therapy.

Document US2012296235 (A1) relates to a system for monitoring of physiotherapy exercises, comprising “motion capture” sensors capable of comparing detected movements with pre-registered data and providing
30 feedback in real time to the user and to the sanitary professional.

- 2 -

Nevertheless, the known solution in US2012296235 (A1) is inefficient for use in water, and further, it does not allow a detection with adequate precision for monitoring of a rehabilitative therapy.

Document EP3067783 (A1) relates to a system and method for tracking of human locomotion that provides for a relative measurement of body segments by means of electromagnetic sensory units, in order to discover the position of the user's feet. The solution known in EP3067783 (A1) is, however, unsuitable for use in water, and further, it does not allow an adequate monitoring of movements during a rehabilitative therapy.

Document US8593286 (B2) relates to a system and method for monitoring of sports activities, wherein inertial sensors are associated with body segments of a user. The solution known in US8593286 (B2) is, however, unsuitable for use in water, and further, it does not allow an adequate monitoring of movements during a rehabilitative therapy.

Document US2015192413 (A1) relates to a method for tracking of body movements by means of a set of sensors associated with body segments, which detect the 3D position and orientation of the segments. The solution known in US2015192413 (A1) is, however, unsuitable for use in water, and further, it does not allow an adequate monitoring of movements during a rehabilitative therapy.

Document US8165844 (B2) relates to a system for tracking of movement comprising a plurality of modules of sensors of movement positioned on various body segments, which capture the 3D position and orientation of the segments. The solution known in US8165844 (B2) is, however, unsuitable for use in water, and further it does not allow an adequate monitoring of movements during a rehabilitative therapy.

In general, the solutions discussed above are unsuitable for the application of monitoring of movements in water, which is instead required in many rehabilitation scenarios, also thermal ones, and for water sports.

The kinematic monitoring of body movements in water presents a technical problem due to the visual obstacle constituted by the reflection and refraction phenomena in water, which render more difficult the

- 3 -

monitoring of movements by visual detection techniques.

Therefore, the operators (therapists or trainers) need solutions that are specifically configured for detection and kinematic monitoring of body movements in water.

5 Document US2013237375 (A1) relates to an apparatus for swimming pool training, for controlling the position of a user inside a tub, and providing luminous visual alarms relating to the position of the swimmer according to predetermined criteria. However, the solution known in US2013237375 (A1) exclusively monitors the position of the swimmer with respect to the
10 edges of the tub, rendering this solution inefficient for monitoring of movements during a rehabilitative therapy.

Document WO2015155069 (A1) relates to a wearable device for performance monitoring of a swimmer in water; such a device comprises heartbeat sensors and inertial movement sensors for detecting the
15 position of the swimmer within an area. However, the device known in WO2015155069 (A1) detects kinematic parameters that are measured only in correspondence of the swimmer's back, rendering it inefficient for monitoring of movements during a rehabilitative therapy.

Document US7980998 (B2) relates to a detection device comprising a
20 single sensor unit, of the inertial type, for monitoring of swimmers' movements, and it further relates to a communication system with which an instructor communicates with a plurality of swimmers, delivering indications relative to the training. However, the device known in US7980998 (B2) detects kinematic parameters, such as absolute position
25 and orientation, which are measured individually for each body part of the swimmer, rendering such a device inefficient for monitoring of movements during a rehabilitative therapy.

Prior art solutions, in general, have the disadvantage of not allowing an efficient detection of body movements during a rehabilitative therapy or
30 physical exercise in water.

Further, prior art solutions, in general, have the disadvantage of not providing an efficient monitoring that constitutes a valid help for the execution of a rehabilitative therapy or of a sports activity.

- 4 -

Summary of invention

An object of the present invention is to solve inconveniences of the background art.

5 A particular object of the present invention is to provide a detection and kinematic monitoring of body movements, executed in a multi-segment manner and that are accurate and reliable.

10 A particular further object of the present invention is to provide a detection and kinematic monitoring of body movements that allow a quantitative supervision of motor gestures, in particular for rehabilitation and sports purposes.

A particular further object of the present invention is to provide a detection and kinematic monitoring of body movements executed in water.

15 A particular further object of the present invention is to provide a detection and kinematic monitoring of body movements that allow sending an immediate and real time feedback, for a possible correction or modification of the ongoing motor gesture.

A particular further object of the present invention is to provide a detection and kinematic monitoring of body movements by means of an optimized processing of the measured data.

20 A particular further object of the present invention is to provide a detection and kinematic monitoring of body movements that are increasingly functional for therapeutic and rehabilitative applications in water.

25 These and other objects are achieved by a system for detection and kinematic monitoring of body movements in water and by a method for detection and kinematic monitoring of body movements in water, according to the features of the appended claims that constitute an integral part of the present disclosure.

30 An idea underlying the present invention is to provide a system for detection and kinematic monitoring of body movements in water, comprising: a wearable device for a user and adapted for use in water,

- 5 -

comprising at least two inertial measurement units (IMU) adapted to be associated with at least two body segments of said user respectively, said body segments defining at least one angle variable with a body movement between them, said at least two inertial measurement units comprising
5 sensors configured to detect kinematic values of said body movement and to convert them into measured data, and further comprising at least one master node connected to said at least two inertial measurement units to collect said measured data, said master node being further configured for an online transmission of said measured data.

- 10 The system for detection and kinematic monitoring further comprises a processing system comprising: a receiver configured for an online reception of said measured data, and further comprising a computer operatively connected to said receiver and configured to reconstruct said body movement of said user in real time starting from said measured data,
15 and further configured to carry out a comparison between said reconstructed body movement and predefined kinematic parameters.

- The system for detection and kinematic monitoring further comprises a feedback system comprising: at least one feedback device configured to receive information relating to said comparison and further configured to
20 deliver at least one indication about said body movement at least to said user based on said information.

Advantageously, the system of the present invention allows to detect and monitor multi-segment body movements in an accurate and reliable manner.

- 25 Further, advantageously, the system of the present invention allows a quantitative supervision of the movement also by the user, that is, by the executor of the movement, with particular advantages in therapeutic, rehabilitative or sports fields.

- In particular, advantageously, the system of the present invention allows
30 the monitoring of the body movement quality both by the user and, optionally, by an operator (therapist or trainer).

Further, advantageously, the system of the present invention allows to provide an immediate real time feedback to the user, for a possible

- 6 -

correction or modification of the ongoing motor gesture.

Advantageously, the system of the present invention is particularly adapted for detection and kinematic monitoring of body movements executed in water.

- 5 Advantageously, the system of the present invention allows an optimized processing of the measured data for the reconstruction of the body movement.

According to a further aspect, an idea underlying the present invention is providing a method for detection and kinematic monitoring of body
10 movements in water, wherein a user wears and uses in water a wearable device, comprising: associating at least two inertial measurement units with at least two body segments of said user respectively, said body segments defining at least one angle variable with a body movement between them, and detecting kinematic values of said body movement by
15 sensors and converting them into measured data; collecting said measured data, transmitting and receiving them online; calculating and reconstructing said body movement of said user in real time starting from said measured data, and carrying out a comparison between said reconstructed body movement and predefined kinematic parameters;
20 delivering at least one indication about said body movement at least to said user based on said comparison.

Further features and advantages will become more evident from the detailed description made hereinafter of non-limiting preferred
25 embodiments of the present invention, and from the dependent claims that outline preferred and particularly advantageous embodiments of the invention.

Brief description of drawings

The invention is illustrated with reference to the following figures, provided as non-limiting examples, wherein:

- 30 – Figures 1a and 1b illustrate an embodiment of a wearable device for a system for detection and kinematic monitoring according to the present invention.

- 7 -

– Figure 2 schematically illustrates an embodiment of a system for detection and kinematic monitoring according to the present invention.

– Figures 3a, 3b, 3c, 3d, 3e, 3f illustrate examples of screens provided by a visual feedback system in a system for detection and kinematic
5 monitoring according to the present invention.

In the different figures, analogous elements will be identified with analogous reference numbers.

Detailed description

Figures 1a and 1b illustrate, in respective front and back views, an
10 embodiment of a wearable device 100 for a system for detection and kinematic monitoring according to the present invention.

The wearable device 100 is suitable for a user and is adapted for use in water, preferably both fresh and salt water, also in a thermal environment. The wearable device 100 supports sensors, which will be further
15 described, for detecting body movements also in water. The wearable device 100, in general, is easy to wear, does not represent an obstacle for the execution of movements and is adjustable in width and length to adapt itself to the user's build.

The wearable device comprises inertial measurement units 101, also
20 called IMU.

Such inertial measurement units 101 are adapted to be associated with body segments of the user respectively, the body segments defining at least one angle variable with a body movement between them. In the preferred embodiment, the inertial measurement units 101 are associated
25 with: forearm, arm, femur, tibia, upper trunk and lower trunk of the user.

In particular, preferably, the wearable device 100 comprises two parts 100a and 100b that can be worn also independently: an upper part 100a in charge of the detection of the movements of upper trunk and upper limbs, and a lower part 100b in charge of the detection of the movements
30 of lower trunk and lower limbs.

In the preferred embodiment, each of the two parts 100a or 100b of the

- 8 -

wearable device 100 comprises five inertial measurement units for monitoring the limbs bilaterally. Only three inertial measurement units could also be used for monitoring a limb unilaterally. It is implied that for monitoring a generic movement of a limb, it would be enough to have at least two inertial measurement units associated with at least two
5 respective body segments adapted to define an angle variable with a movement between them.

In general, among such at least five inertial measurement units 101 of the parts 100a or 100b, two are associable with distal portions of limbs
10 respectively (forearm or tibia), further two are associable with proximal portions of limbs respectively (humerus or femur), and one is associable with a trunk portion (upper or lower) of the user respectively.

In general, the inertial measurement units 101 comprise sensors configured to detect kinematic values of a body movement and to convert
15 them into measured data. In particular, such sensors comprise accelerometers, gyroscopes and geomagnetic sensors. In a preferred embodiment, each inertial measurement unit 101 comprises a triaxial accelerometer, a triaxial gyroscope, a triaxial geomagnetic sensor and a microcontroller in charge of the interpretation and conversion of the
20 kinematic values detected into measured digital data.

The wearable device 100 further comprises at least one master node 102, connected to the inertial measurement units 101 to collect the measured data.

Preferably, the master node 102 is connected to the inertial measurement
25 units 101 by means of wired connections, in particular with waterproof connectors. In general, the inertial measurement units 101 and the master node 102 comprise waterproof casings.

In an example, the inertial measurement units 101 form a sensor network operated at the master node 102 level. Each sensor node 101 collects the
30 data independently but is connected by means of a connector (preferably with IP68 protection) to the master node 102. The master node 102 is capable of reading the data from all the sensor nodes 101 by means of an appropriate communication protocol.

- 9 -

In the preferred embodiment, the master node 102 comprises an electric battery for powering the inertial measurement units 101 connected to it.

The master node 102 is further configured for an online transmission of the measured data. Preferably, the master node 102 comprises an online
5 wireless transmitter, in particular at a sampling frequency of 20 Hz, preferably using a Wi-Fi or MiWi communication protocol at 0.9 GHz.

Preferably, the master node 102 is at least partially positioned, in the wearable device 100, in an emerged position when it is used in water, to improve the data transmission.

10 Advantageously, the wearable device 100 does not require a positioning of the inertial measurement units 101 in precise coordinates on the various body segments of the user, thanks to a specific calibration procedure that will be further described.

Figure 2 schematically illustrates an embodiment of a system for detection
15 and kinematic monitoring 200 according to the present invention.

The system for detection and kinematic monitoring 200 comprises the wearable device 100 already described; for exemplification purposes, the user that wears the wearable device 100 is immersed in a tub or swimming pool 2.

20 The system for detection and kinematic monitoring 200 also comprises a processing system 201. The processing system 201 comprises a receiver 202 that is configured for online reception of the measured data by the master node 102, as already described.

In the present description, the term “online” is intended as “that
25 substantially takes place in real time”, that is, that allows – in a manner that is clear to the person skilled in the art – detection and monitoring instant by instant, simultaneously with the execution of the movement, except for a slight delay due to the transmission and processing of the data.

30 The processing system 201 further comprises a computer 203 operatively connected to the receiver 202 and configured to reconstruct the body movement of the user in real time starting from the measured data.

- 10 -

Further, the computer 203 is configured to carry out a comparison between the reconstructed body movement and predefined kinematic parameters, that is, “goal” parameters for the movement requested to the user.

- 5 The computer 203 is configured to reconstruct the body movement in real time, by means of the calculation of at least a relative angle measured between at least two inertial measurement units 101.

In general, the processing system 201 is adapted to reconstruct the body movement of the user in real time, cooperating with the measured data by
10 means of the wearable device 100, as exemplified below.

Each of the inertial measurement units 101 measures its own angular movement with respect to a fixed reference system, identified by the direction of the acceleration of gravity or by the north magnetic pole.

In order to estimate the angles of the joints, it is necessary to measure the
15 orientation of two adjacent body segments. In this embodiment, the articular angles of the upper limbs and of the lower limbs are alternatively measured, and in particular, for the cage of the upper limb, the angles of the shoulder and of the elbow are estimated, both for the lower limbs and for the angles of the hip and of the knee. The implicit assumptions of the
20 approach presented are: i) the joints are modeled as spherical joints; ii) each sensor is fixed with respect to the body segment thereof (that is, the relative movement due to muscles or tissue movement is neglected); iii) limbs and back are modeled as rigid segments.

Three sensors are preferably used for monitoring three respective nodes: -
25 a reference node that is preferably placed on the back part (when the upper limbs are monitored) or on the pelvis (when the lower limbs are monitored); - an upper node that is positioned on the arm (during the monitoring of the upper limbs) or on the thigh (during the monitoring of the lower limbs); - a lower node, positioned on the forearm (during the
30 monitoring of the upper limbs) or on the tibia (during the monitoring of the lower limbs).

The sensors must be positioned on the corresponding segment, but, advantageously, it is not necessary that the exact positioning is repeatable

- 11 -

for different sessions.

The angles of the body segments are preferably calculated according to the conventions provided by the International Society of Biomechanics (ISB).

5 Preferably, the processing system 201 is configured to carry out a static calibration step and a subsequent dynamic calibration step to reconstruct the body movement of the user.

In the static calibration step, a calibration is carried out wherein at least two inertial measurement units are in a condition in which the respective at least two body segments are aligned according to the same axis.

10 In the dynamic calibration step, a subsequent calibration is carried out by means of the detection of an angle variation, preferably by an angle of less than 20 degrees, between the at least two inertial measurement units with a body movement in the sagittal plane of said user.

15 Advantageously, both the static calibration step and the dynamic calibration step can be carried out before the user is immersed in the tub or pool 2, thus being able to control in a visual manner the quality of the movement executed by the user during the dynamic calibration step.

20 The system for detection and kinematic monitoring 200 also comprises a feedback system. The feedback system comprises at least a feedback device 204, configured to receive information relating to the comparison between the reconstructed movement and the predefined kinematic parameters.

25 Further, the feedback system is configured to provide, based on said information, at least one indication about the body movement, wherein such an indication is provided at least to the user in the tub or pool, who is capable of taking advantage of the signal of the feedback device 204.

Preferably, the predefined kinematic parameters comprise amplitude and/or execution speed of a movement, to give feedback to the user in real time on the quality of execution of a given movement.

30 The feedback device 204 preferably comprises a display or an earphone or a tactile element in the wearable device 100, so as to deliver to the user an

- 12 -

indication of visual or acoustic or tactile type (for example, a vibration) to increase awareness of his/her own body position and of the movements that the user executes.

5 The indication on the execution quality of a given movement is particularly configured for control of amplitude and/or of execution speed of the body movement by the user.

10 Preferably, the feedback system comprises at least one second feedback device 205 for an operator 3, preferably a display associated with the computer 203. Such a second feedback device 205 is adapted to deliver second information relating to the reconstructed body movement and to the performed comparison. Thus, the second feedback device 205 is configured to deliver at least one indication about the body movement also to the operator 3 based on the second information. In particular, the operator 3 is a trainer or a therapist that monitors the session of the user
15 in the tub or pool 2.

Advantageously, the second feedback device 205 can deliver an alarm signaling every time the wearable device 100 detects the fall of the trunk with respect to the gravitational axis, potentially indicative of a loss of balance or of the risk of drowning of the user in the tub 2, during a
20 rehabilitation session.

In general, the method for detection and kinematic monitoring according to the present invention can be implemented in the system 200 for detection and kinematic monitoring of body movements in water according to the present invention. The features of the latter therefore refer also to
25 the method, according to what has been described here.

Figures 3a, 3b, 3c, 3d, 3e, 3f illustrate examples of screens provided by the feedback device 204 or 205 in case of visual feedback. The user interface is called "biofeedback" interface, in the following.

30 The feedback device 204 can interface with users under medical care or elderly people, providing the simplest and most comprehensible output possible, while still keeping a sufficient level of informative content. During the therapy in water, the user is typically not capable of using glasses; the basic visual outputs have been selected to be appropriately

- 13 -

well legible.

As it can be seen in Figure 3a, the user interface preferably comprises two stylized human figures 301 and 302 that represent the initial and final positions of the movement, and a cursor 303 connected to the selected articulation to be representative of the exercise, for example the elevation of the shoulder in a range 304.

As it can be seen in Figure 3b, visual feedback is provided to the user based on the position thereof: different background colors 306 advise the user when he/she approaches the goals. In the top right angle, number 305 indicates the repetitions so far executed out of the total requested.

As it can be seen in Figure 3c, a further movement angle can be monitored, in connection with the biofeedback resulting in a notice 307, for example a red exclamation mark, every time a corresponding threshold is exceeded. For instance, during the exercises for the shoulder, the elbow must remain extended. In this case, the angle of the elbow can be selected as monitored secondary angle. In the example, when the user bends the elbow beyond an operator-defined threshold, it appears the red exclamation mark 307 reminding the user to keep the elbow extended.

Three biofeedback modes have been designed, and in particular:

“Amplitude control biofeedback”: the user is led to execute an angular excursion previously defined by the operator at a self-stimulation speed. The user can interrupt it at any moment.

“Amplitude/speed control biofeedback”: the user is required to execute an angular excursion previously defined by the operator at a defined speed. A negative feedback (such as the turtle 308 of Figure 3d) is provided when the speed of movement is inferior to the requested one.

“Tutor Biofeedback”: the user is requested to execute an angular excursion previously defined by the operator at a defined speed following a virtual tutor. In the training progression bar, beside the cursor connected to the chosen articular angle for representing the exercise (for example, elevation of the shoulder for the exercises of abduction of the shoulder / adduction), a second cursor 309 is shown, as can it be seen in Figure 3e,

- 14 -

which represents the desired articulation position). A green-yellow-red color code is preferably adopted for the angular excursion bar, so that the bar itself advises the user when the absolute distance between the two pointers increases. After the execution of a complete movement, the user is requested to wait in rest position by a countdown, before proceeding with the new repetition.

As it can be seen in Figure 3f, during the movements of the whole body, a dedicated biofeedback modality is provided called “Rhythm monitoring biofeedback”: the user interface consists of a foot silhouette that represents the position of the starting movement and a “step” indicator, which shows the performance (average values of the last 5 repetitions, indicated as [step/minute]) of the session in progress.

The feedback system shows selected parameters optimized for the user’s needs, so as to give the user an online feedback about the correctness of execution of the rehabilitation exercise or of the movement in general.

By means of the monitoring interface of the operator, preferably displayed on the feedback device 205, the operator is given the possibility to personalize the exercise for the current user and to decide which angles to monitor in real time. It is therefore possible to select and customize which parameters are shown by the feedback system, acting on an interface at the disposal of the operator (therapist or trainer).

At the end of each training session, the user’s performance is assessed with a score system, for instance in a scale between 0 and 100, rendering possible a quick comparison of the sessions over time, thus keeping the user monitored and motivated.

Preferably, the computer 203 is operatively connected to at least one memory and configured to store the measured data for a subsequent processing. Thus, the operator (therapist/trainer) can access detailed reports of the rehabilitation or body movement session, with a complete description of the kinematics of all the movements of the various segments monitored, to assess the user’s performance.

Industrial applicability

- 15 -

The applications of the presented system potentially range from rehabilitation to athletic training to research in the field of aquatic kinematics.

5 Since the biofeedback allows a quicker and more efficient recovery, the system of the present invention can be applied for the therapy of orthopedic and rheumatic diseases accompanied by general symptomatology: subacute and chronic pain syndromes, ROM reduction, post-injury recovery of soft tissue or bone, and post-operative recovery; scoliosis correction and pain management, especially for backache; sports
10 traumatology and vertebral column trauma.

The system of the present invention can be applied also for neurological disorders, wherein both the biofeedback and the microgravity condition during immersion in water (that allows the movement also in case of significant motor deficit) may provide precise indications.

15 The aquatic movements guided by the biofeedback advantageously allow the stimulation of the residual cognitive functions of patients.

Thanks to the movement analysis functions, the system according to the present invention could also be used for prevention, allowing the doctor to anticipate the detection of changes associated to certain pathological
20 conditions.

Considering the description herein provided, the person skilled in the art will be able to devise further modifications and variants in order to satisfy contingent and specific needs. The embodiments described here are therefore to be intended as illustrative examples and not limitative of the
25 invention.

- 16 -

CLAIMS

1. System for detection and kinematic monitoring of body movements in water, comprising:

5 a wearable device (100) for a user and adapted for use in water, comprising:

- at least two inertial measurement units (101) adapted to be associated with at least two body segments of said user respectively, said body segments defining at least one angle variable with a body movement between them, said at least two inertial measurement units (101) comprising sensors configured to detect kinematic values of said body movement and to convert them into measured data,

10 - and further comprising at least one master node (102) connected to said at least two inertial measurement units (101) to collect said measured data, said master node (102) being further configured for an online transmission of said measured data;

15 a processing system (201) comprising:

- a receiver (202) configured for an online reception of said measured data,

20 - and further comprising a computer (203) operatively connected to said receiver (202) and configured to reconstruct said body movement of said user in real time starting from said measured data, and further configured to carry out a comparison between said reconstructed body movement and predefined kinematic parameters;

a feedback system comprising:

25 - at least one feedback device (204) configured to receive information relating to said comparison and further configured to deliver at least one indication about said body movement at least to said user based on said information.

2. System according to claim 1, wherein said at least two inertial measurement units (101) and said at least one master node (102)

30

- 17 -

comprise waterproof casings.

3. System according to claim 2, wherein said master node (102) is connected to said at least two inertial measurement units (101) by means of at least one wired connection, in particular a wired connection with waterproof connectors, said master node (102) being at least partially positioned, in said wearable device, in a position emerged during said use in water.

4. System according to claim 3, wherein said master node (102) comprises an online wireless transmitter, preferably using a Wi-Fi or MiWi communication protocol.

5. System according to any one of claims 1 to 4, wherein said sensors configured to detect kinematic values comprise accelerometers, gyroscopes and geomagnetic sensors.

6. System according to any one of claims 1 to 5, wherein said wearable device (100) comprises at least five inertial measurements units (101), two thereof (101) are associable with distal portions of limbs respectively, further two thereof (101) are associable with proximal portions of limbs respectively, and one thereof (101) is associable with a trunk portion of said user respectively.

7. System according to any one of claims 1 to 6, wherein said computer (203) is configured to reconstruct said body movement in real time by means of calculation of at least one relative angle between said at least two inertial measurement units.

8. System according to claim 7, wherein said processing system (201) is configured to carry out a static calibration step and a subsequent dynamic calibration step to reconstruct said body movement of said user,

wherein said static calibration step is configured by means of said at least two inertial measurement units (100), being said at least two body segments aligned according to the same axis,

and wherein said dynamic calibration step is configured by means of detection of an angle variation, preferably by an angle less than 20 degrees, between said at least two inertial measurement units (100) with a

- 18 -

body movement in the sagittal plane of said user.

9. System according to any one of claims 1 to 8, wherein said predefined kinematic parameters comprise amplitude and/or execution speed.

5 10. System according to any one of claims 1 to 9, wherein said feedback device (204) comprises a display or an earphone or a tactile element of said wearable device, and wherein said at least one indication delivered to said user is of visual or acoustic or tactile type.

10 11. System according to claim 10, wherein said at least one indication is configured for control of amplitude and/or of execution speed of said body movement of said user.

12. System according to any one of claims 10 or 11, wherein said feedback system comprises at least one second feedback device (205) for an operator, preferably a display, adapted to deliver second information
15 relating to said reconstructed body movement and to said comparison, and further configured to deliver at least one indication about said body movement to said operator based on said second information.

13. Method for detection and kinematic monitoring of body movements in water, wherein a user wears and uses in water a wearable device (100),
20 comprising:

- associating at least two inertial measurement units (101) with at least two body segments of said user respectively, said body segments defining at least one angle variable with a body movement between them, and detecting kinematic values of said body movement by sensors and
25 converting them into measured data;

- collecting said measured data, transmitting and receiving them online;

- calculating and reconstructing said body movement of said user in real time starting from said measured data, and carrying out a
30 comparison between said reconstructed body movement and predefined kinematic parameters;

- 19 -

- delivering at least one indication about said body movement at least to said user based on said comparison.

14. Method according to claim 13, wherein at least one relative angle between said at least two inertial measurement units (101) is calculated
5 and said body movement of said user is reconstructed, and further comprising:

carrying out a static calibration step wherein said at least two inertial measurement units (101) are on said at least two body segments that are aligned according to the same axis,

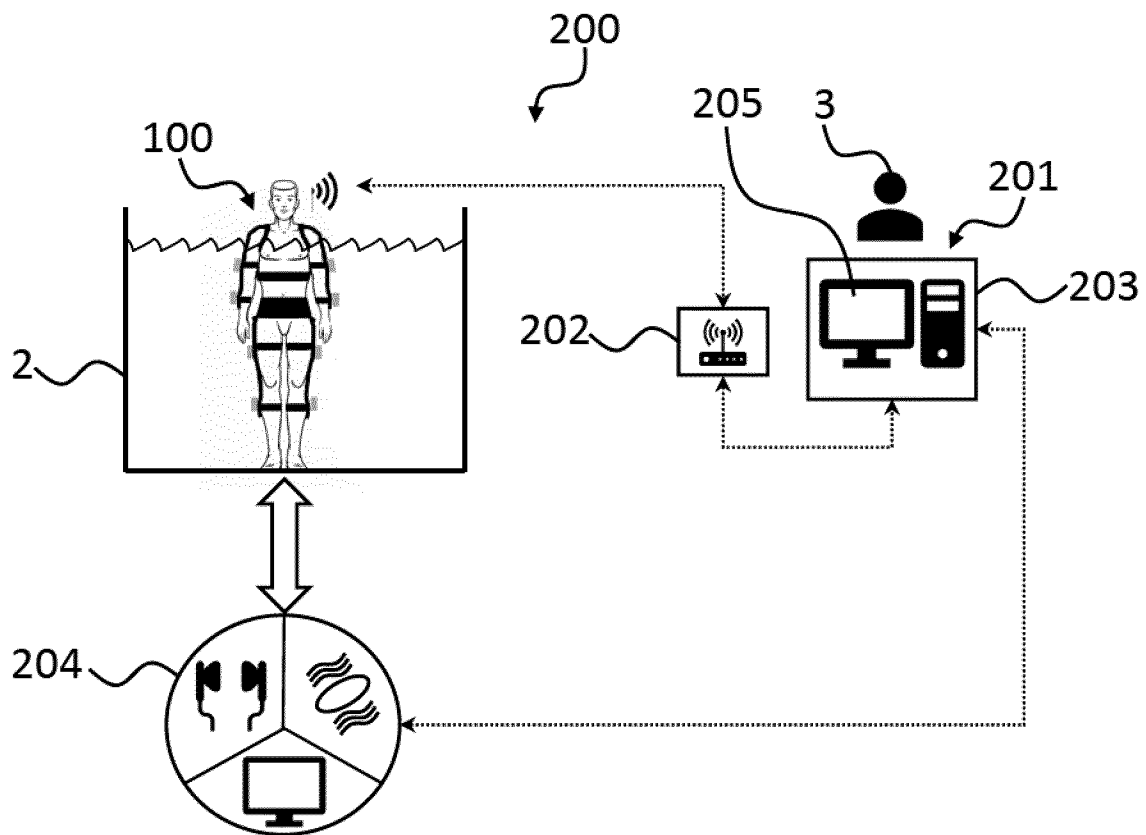
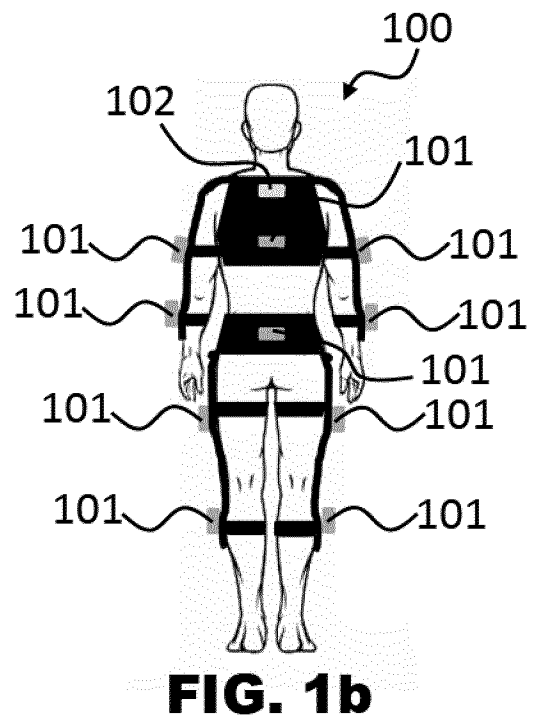
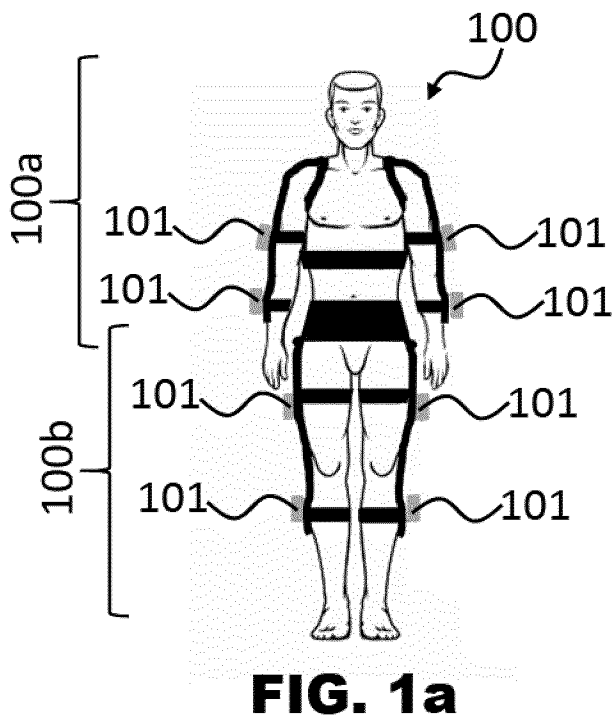
10 carrying out a subsequent dynamic calibration step, detecting an angle variation, preferably by an angle less than 20 degrees, between said at least two inertial measurement units (101) with a body movement in the sagittal plane of said user.

15 15. Method according to claim 13 or 14, which is implementable in a system (100) for detection and kinematic monitoring of body movements in water according to any one of claims 1 to 12.

20

25

- 1/3 -



- 2/3 -

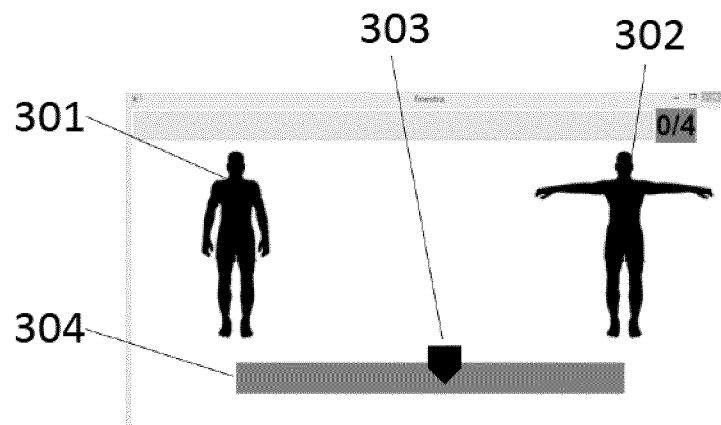


FIG. 3a

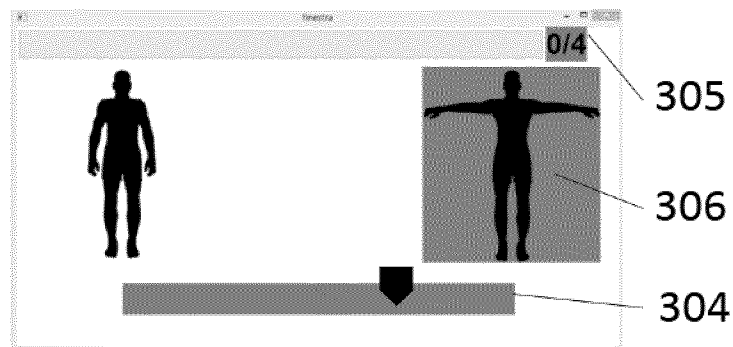


FIG. 3b

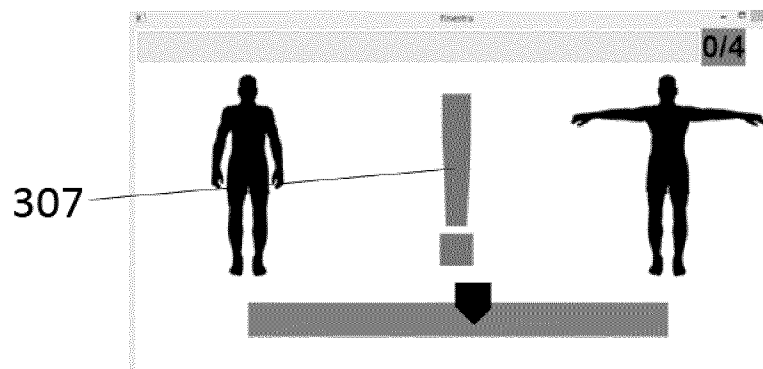


FIG. 3c

- 3/3 -

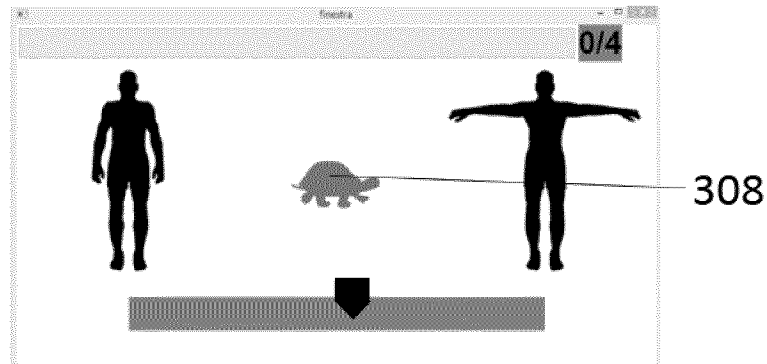


FIG. 3d

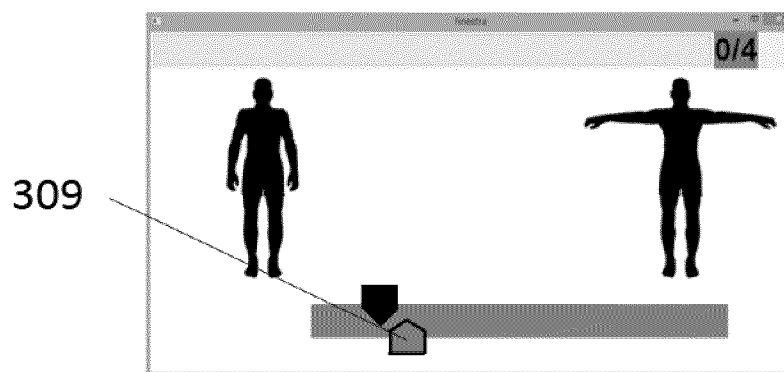


FIG. 3e

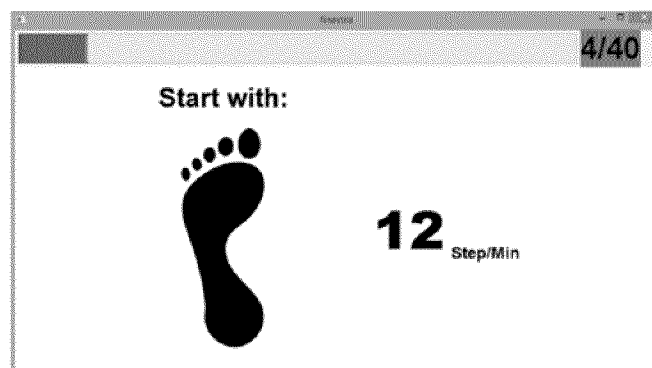


FIG. 3f

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/067618

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00 A61B5/11
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)
G06K 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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/032315 A1 (SHEMESH ELDAD [IL]; SHEMESH-GRANOT LIAT [IL]) 20 March 2008 (2008-03-20) abstract; figures 1-3,9,10 page 13 - page 21 -----	1-15
X	US 2012/139731 A1 (RAZOUMOV LEONID [US] ET AL) 7 June 2012 (2012-06-07) paragraph [0031] - paragraph [0040] -----	1-15
A	WO 2015/110298 A1 (ICURA APS [DK]) 30 July 2015 (2015-07-30) page 5 - page 7; figure 3 ----- -/-	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

29 July 2019

Date of mailing of the international search report

05/08/2019

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) 340-3016

Authorized officer

Alecu, Teodor Iulian

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/067618

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Anonymous: "Does Wi-Fi work underwater? - Quora", 29 March 2016 (2016-03-29), XP055571269, Retrieved from the Internet: URL:https://www.quora.com/Does-Wi-Fi-work-underwater?share=1 [retrieved on 2019-03-19] the whole document -----	3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/067618

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008032315 A1	20-03-2008	US 2009239710 A1 WO 2008032315 A1	24-09-2009 20-03-2008
US 2012139731 A1	07-06-2012	NONE	
WO 2015110298 A1	30-07-2015	EP 3096685 A1 US 2017000388 A1 WO 2015110298 A1	30-11-2016 05-01-2017 30-07-2015