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(54) **ROCKING BED, METHOD AND COMPUTER PROGRAM FOR OPERATING A ROCKING BED**

(57) The invention relates to a rocking bed (1), comprising a slider-crank mechanism (2 comprising a rotary drive (3) and at least one four-bar linkage (4) comprising a frame (5) with two cranks (6) pivotably mounted thereon via a first pivot (P1) and a second pivot (P2), and a movable linkage (7) pivotably connected to the cranks via a third pivot (P3) and a fourth pivot (P4), wherein a connecting rod (21) of the slider-crank mechanism (2) is pivotably connected to a support structure (8) of the rocking bed (1) via a sixth pivot (P6), wherein there is a pivotable connection between the movable linkage (7) and the support structure (8) of the rocking bed (1) via a fifth pivot (P5), via which a movement of the support structure (8) can be guided along a horizontal direction and wherein the rotary drive (3) has a control unit configured to realize a revolution operation of a crank (22) of the slider-crank mechanism (2).

The invention also relates to a method as well as a computer program for operating such a rocking bed (1).

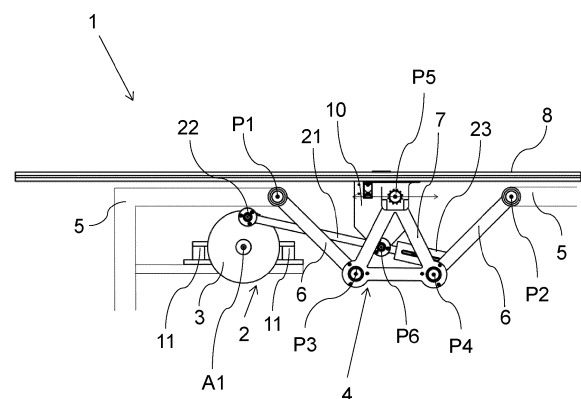


Fig. 2

Description

[0001] The present invention relates to a rocking bed, a method for operating a rocking bed and a computer program for operating a rocking bed.

[0002] Rocking beds find broad applications in the commercial sector, where the rocking motion is perceived as comfortable by persons resting on the rocking bed, but also in the medical sector, where rocking beds are used to study and treat sleep-related disorders.

[0003] The rocking motion typically involves a relative movement between a supporting structure, on which the person may rest, as well as a frame, which supports the supporting structure. To realize the rocking motion, rocking beds comprising wheels and/or guide rails for supporting the supporting structure on and moving it with respect to the frame are known. However, due to friction, there may be jerks in the movement. Some of these jerks of the wheel-rail approach are due to the stick-slip effect, which causes undesired abrupt accelerations in the turning points of the back-and forth movement. At the same time, the friction typically causes sleep disturbing noises.

[0004] For example, DE102009030736A1 discloses a pendulum couch with a frame as well as a guide allowing a pendulum movement of the couch relative to the frame. The pendulum movement is realized by two coupling gears provided between the frame and the couch. However, due to the construction of the coupling gears, driving the movement requires a motor that allows for a reversal of the direction of rotation at the reversal points of the pendulum motion, which results in strong stick-slip effects.

[0005] Moreover, WO2007053416A2 discloses a rocking bed with a frame capable of being in a rocking motion with respect to two support structures, wherein pairs of linkages are secured to the support structures and the frame. A drive mechanism is configured to generate the rocking motion under continuous rotation of a crank of a slider crank mechanism, such that stick slip effects related to repeated changes of the rotation direction of the crank are avoided. However, as a consequence of the structure of the linkages, the rocking motion is generally not restricted to a horizontal plane, but also comprises fairly large vertical components, which can be perceived as disturbing by a person resting on the bed.

[0006] Other approaches focus on suspended rocking beds suspended from a ceiling and actuated using ropes that are guided through an array of pulleys. However, this approach is typically difficult to control and requires a lot of maintenance. For instance, as the stiffness of the rope changes over time, regular re-calibrations are needed.

[0007] Based on the above, it is subject of the present invention to provide a rocking bed that allows for smoother and essentially horizontal movements, while being less noisy and easier to use compared to the rocking beds of the prior art. It is also subject of the invention to provide a method as well as a computer program for operating a rocking bed.

[0008] This task is solved by a rocking bed with the features of claim 1, a method for operating a rocking bed with the features of claim 14, as well as a computer program for operating a rocking bed with the features of claim 15.

[0009] Advantageous embodiments of the invention are given in the corresponding dependent claims and described in the following.

[0010] A first aspect of the invention relates to a rocking bed comprising a slider-crank mechanism comprising a rotary drive and at least one four-bar linkage comprising a frame. Two cranks are pivotably mounted on the frame via a first and a second pivot. A movable linkage is pivotably connected to the cranks via a third and a fourth pivot, wherein a connecting rod of the slider-crank mechanism is pivotably connected to a support structure of the rocking bed via a sixth pivot. There is a pivotable connection between the movable linkage and the support structure of the rocking bed via a fifth pivot, via which a movement of the support structure can be guided along a horizontal direction. The rotary drive has a control unit configured to realize a revolution operation of a crank of the slider-crank mechanism.

[0011] The slider-crank mechanism can be operated by the rotary drive, wherein the rotary drive sets the crank of the slider-crank mechanism into rotation around a rotation axis of the crank of the slider-crank mechanism. The rotation of the crank of the slider-crank mechanism can be converted into a relative lateral movement between the support structure and the frame via the connecting rod connecting the crank of the slider-crank mechanism and the support structure.

[0012] The first, second, third, fourth and fifth pivot define respective distances between the first and the third pivot, the third and the fourth pivot, the third and the fifth pivot, the fifth and the fourth pivot as well as the fourth and the second pivot. Depending on the ratios between the respective distances, the movement of the support structure with respect to the frame may also comprise deviations from a horizontal direction, that is, along a vertical direction perpendicularly to the horizontal direction.

[0013] The revolution operation of the crank of the slider-crank mechanism realizable by the control unit of the rotary drive is such that the crank of the slider-crank mechanism rotates completely, that is, by a rotation of at least 360° degrees, around its rotation axis, making it a revolution operation. In particular, the revolution operation comprises multiple revolutions around the rotation axis with the same sense, such that the support structure is moved repeatedly back and forth with respect to the frame. The revolution operation of the crank of the slider-crank mechanism advantageously reduces the slip-stick-effect: Typically, for a relative displacement between two elements contacting each other, the static friction coefficient is larger than the kinetic friction coefficient, for example the sliding friction coefficient. If the two elements are to be moved with respect to each other, the larger

static friction coefficient requires a force to overcome the static friction force which is larger than the force required to overcome the kinetic friction coefficient, causing an abrupt onset of the relative movement every time the two elements are moved with respect to each other from a resting position. In contrast, the revolution operation of the crank of the slider-crank mechanism causes the support structure to be repeatedly moved back and forth with respect to the frame under continuous rotation of the crank of the slider-crank mechanism, such that slip-stick-effects related to the rotary drive, the slider-crank mechanism and the pivot connecting the connecting rod of the slider-crank mechanism with the support structure are avoided. At the same time, the mechanical connection between frame and the support structure via the four-bar linkage and the six pivots keep friction forces between the frame and the support structure low, which further reduces the slip-stick effect. As a result, the rocking motion of the support structure describes a smooth trajectory as function of time, which is perceived as comfortable by a user resting on the support structure.

[0014] An amplitude of the relative movement between the support structure and the frame, that is, the maximum relative displacement between the support structure and the frame during one revolution of the crank of the slider-crank mechanism depends on the distance between the crank of the slider-crank mechanism and its rotation axis and may be, for example, up to 150 mm, particularly 100 mm.

[0015] Preferably, the support structure is configured such that a person may lay down on it or on a cushion structure such as a mattress arranged on the supporting structure.

[0016] According to an embodiment, the fifth pivot is arranged outside an imaginary linear connection between the third and the fourth pivot. By this measure, the third, fourth and the fifth pivot form a triangle between the cranks connecting the movable linkage and the frame, which allows to realize an essentially horizontal movement of the fifth pivot and thus the support structure, such that the four-bar linkage acts as a Roberts linkage.

[0017] In another embodiment, the fifth pivot and the first and the second pivot are arranged between two imaginary horizontal planes comprising a spacing of delta y, wherein delta y is smaller than a distance l_1 between the first and the third pivot and/or between the second and the fourth pivot. In particular, delta y equals x/l_1 , with x being between -0.5 and 1, more preferably with x being between 0 and 0.3. For positive values of delta y, the fifth pivot is arranged on a first side with respect to an axis connecting the first and the second pivot, for negative values of delta y, the fifth pivot is arranged on a second side with respect to the axis connecting the first and the second pivot opposite to the first side. Correspondingly, the support structure may move vertically with respect to the frame in a range of up to 50 mm, preferably in a range of 0 mm to 10 mm, even more preferably in a range of 0 mm to 1 mm. By this measure,

the ranges of the respective distances between the first, second, third, fourth and fifth pivot that allow to realize an essentially horizontal movement of the fifth pivot and thus the support structure are particularly large.

[0018] According to an embodiment:

- a distance between the third and the fourth pivot is l_2 , with l_1/l_2 being between 1.2206 and 2.5467,
- the distance between the third and the fifth pivot and a distance between the fourth and the fifth pivot is l_3 , with l_1/l_3 being between 1.0015 and 1.9291 and/or
- the distance between the first and the second pivot is l_4 , with l_1/l_4 being between 0.4568 and 0.8444.

[0019] Particularly, a ratio l_5/l_2 , with l_5 being a length of a perpendicular from said imaginary connection to the fifth pivot, is between 1.112 and 1.222.

[0020] For the above ranges of distances, solutions for equations of motion of the pivots under rotation of the slider-crank mechanism can be found, for which the support structure exhibits an almost perfectly horizontal movement with deviations of less than 0.5 mm along the vertical direction perpendicularly to the horizontal plane, which is perceived as comfortable by a user resting on the supporting structure. These ranges have been calculated for a maximum displacement of 100 mm of the support structure and the frame, wherein the fifth pivot is aligned with an axis extending through the first and the second pivot in a resting position in which the fifth pivot resides exactly in the middle between the first and the second pivot.

[0021] For example, l_1 is between 10 mm and 1000 mm, particularly between 100 mm and 500 mm, more particularly between 200 mm and 400 mm.

[0022] In yet another embodiment, the fifth pivot is arranged on a first side of the axis extending through the first and the second pivot and the third and the fourth pivot are arranged on a second side of said axis opposite to the first side. This measure advantageously increases the respective ranges of distances between the pivots compared to the ranges indicated above, for which an almost perfectly horizontal movement of the support structure can be achieved.

[0023] According to an embodiment, a rotation axis of the crank of the slider-crank mechanism is rotatably attached to the frame. As such, the rocking bed may be transported as a unit, that is, including the slider-crank mechanism.

[0024] In an alternative embodiment, the rotation axis of the crank of the slider-crank mechanism is attached to an external structure that is not part of the rocking bed. For example, the external structure is a wall or a floor of a room in which the rocking bed is located or any other object that allows to operate the crank of the slider-crank mechanism with its rotation axis being fixed with respect to the support structure of the bed.

[0025] In another embodiment, the crank of the slider-crank mechanism comprises a plurality of receptacles for

receiving the connecting rod, wherein the receptacles are arranged at different radial distances to the rotation axis of the crank of the slider-crank mechanism, such that a radial distance between the rotation axis of the crank and a pivot connection connecting the connecting rod and the crank of the slider-crank mechanism and thus a maximum deflection amplitude of the relative movement between the support structure and the frame can be changed. As such, different relative displacements between the support structure and the frame may be realized with one and the same slider-crank mechanism.

[0026] According to an embodiment, the crank of the slider-crank mechanism is formed by and acts as a flywheel. As such, the crank is configured to store rotational energy comprised in the revolution operation of the crank, which reduces the energy consumption of the rocking bed.

[0027] In particular, the flywheel comprises the plurality of receptacles for receiving the crank of the slider-crank mechanism, such as a plurality of holes, arranged in different distances with respect to a rotation axis of the flywheel, such that the crank of the slider-crank mechanism can be arranged in different distances to the rotation axis of the flywheel for changing the maximum deflection amplitude of the relative movement between the support structure and the frame.

[0028] In another embodiment, the connecting rod of the slider-crank mechanism extends beyond the sixth pivot with a portion that comprises a counterweight. The counterweight allows to generate a torque equilibrium around the sixth pivot, which mitigates the effect of the mass of the connecting rod on the horizontal movement of the support structure. This measure further contributes to a smooth movement of the support structure with respect to the frame.

[0029] Particularly, the counterweight may be fastened such on the connecting rod that a position of the counterweight with respect to the sixth pivot may be adjusted, for example by means of long holes and bolts to fasten the counterweight in different positions with respect to the sixth pivot. As such, the torque around the sixth pivot may be further reduced by adjusting the position of the counterweight with respect to the sixth pivot.

[0030] According to an embodiment, the rocking bed comprises at least three four-bar linkages, wherein the plurality of four-bar linkages is arranged on the same frame. In particular, the rocking bed comprises exactly four four-bar linkages. As such, the at least three four-bar linkages may be arranged such that they support the support structure on the frame, without additional mechanical connections between the support structure and the frame. Consequently, in this embodiment, stick-slip effects related to frictional forces are further reduced, which improves the smoothness of the movement of the support structure with respect to the frame. In particular, the plurality of four-bar linkages can be set into motion by a single slider-crank mechanism. To this end, the slider-crank mechanism can be connected to one or more of the

four-bar linkages via their respective sixth pivot. For example, two four-bar linkages can be arranged parallel to each other along a longitudinal axis of the rocking bed, wherein the two four-bar linkages are connected to the slider-crank mechanism via a common axis extending through the respective sixth pivot of the two four-bar linkages. The motion of the single slider-crank mechanism can also be transferred to the plurality of four-bar linkages or between the four-bar linkages by further linkages connecting the slider-crank mechanism to the four-bar linkages or connecting four-bar linkages between each other.

[0031] In an alternative embodiment, the rocking bed comprises only one or two four-bar linkages. In this embodiment, the rocking bed may comprise further structures configured to support the support structure on the frame as well as to guide the movement of the support structure along the horizontal direction. For example, the further structures comprise rollers or guide rails.

[0032] In another embodiment, the control unit is configured to adjust a driving velocity of the crank of the slider-crank mechanism based on a first velocity profile of the movement of the support structure with respect to the frame determined for a constant driving velocity of the crank during at least one revolution of the crank around the rotation axis of the slider-crank mechanism, such that for an adjusted driving velocity, the support structure exhibits a second velocity profile, wherein the second velocity profile comprises less deviations from a sinusoidal velocity profile than the first velocity profile. As such, the control unit may be configured to adjust the movement of the support structure toward a perfectly sinusoidal motion by decreasing the determined deviations from a perfectly sinusoidal motion, which are caused by the finite length of the connecting rod between the crank of the slider-crank mechanism and the sixth pivot as well as possible vibrations transmitted from the rotary drive to the support structure. The deviations from a perfectly sinusoidal motion may be reduced for example using a control loop, fitting algorithms and/or a neuronal network providing the adjusted driving velocities to the rotary drive.

[0033] The driving velocity can be controlled by the rotary drive based on input signals from the control unit, particularly based on input signals from a driving velocity controller comprised by the control unit.

[0034] Alternatively, beyond constant driving velocities and adjusted frequencies aiming at a sinusoidal driving velocity, the driving velocity may be set according to predetermined patterns, for example according to on immersive vehicle simulations, such as train or car rides based on recorded motion patterns of vehicle rides. Particularly, the driving velocity may comprise periodic and/or non-periodic, particularly random artificial stutters and vibrations of predefined velocities and accelerations. The artificial stutters may be synchronized with a sound file, reproducing tactile sensations matching the sound events.

[0035] In yet another embodiment, the rocking bed

comprises at least one sensor, wherein the sensor is configured to record movements, electromagnetic signals, electromagnetic radiation and/or sounds and to generate signals indicative of the movements, the electromagnetic signals, the electromagnetic radiation and/or the sounds and to send the signals to the control unit. The sensor may also be configured to record or measure at least one of the following: brain activity, particularly EEG; oxygen saturation, particularly SpO₂; heart activity, particularly ECG or BCG; nasal flow; radar signals. The movements, electromagnetic signals, electromagnetic radiation and/or sounds can be related and/or caused by a person, particularly a person located on the support structure.

[0036] In an embodiment, the control unit is configured to adjust the revolution operation of the crank of the slider-crank mechanism based on the signals received from the at least one sensor.

[0037] A second aspect of the invention relates to a method for operating a rocking bed according to one of the first aspect of the invention, wherein the control unit causes the rotary drive of the slider-crank mechanism to realize a full revolution operation of the crank of the slider-crank mechanism around a rotation axis of the slider-crank mechanism, such that the support structure is moved back and forth relative to the frame by means of forces transmitted from the connecting rod of the slider-crank mechanism to the support structure.

[0038] A third aspect of the invention relates to a computer program for operating a rocking bed, comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method according to the second aspect of the invention.

[0039] In particular, the embodiments of one aspect of the invention are applied to another aspect of the invention, particularly the two other aspects of the invention.

[0040] Exemplary embodiments are described below in conjunction with the Figures. The Figures are appended to the claims and are accompanied by text explaining individual features of the shown embodiments and aspects of the present invention. Each individual feature shown in the Figures and/or mentioned in the text of the Figures may be incorporated (also in an isolated fashion) into a claim relating to the first, second and/or the third aspect according to the present invention.

Fig. 1 shows an embodiment highlighting a four-bar linkage of a rocking bed according to the invention;

Fig. 2 shows an embodiment of a rocking bed according to the invention in a side view;

Fig. 3 shows an embodiment of the crank of the slider-crank mechanism according to the invention, wherein the crank is a flywheel;

Fig. 4 shows a first velocity profile of the support structure with respect to the frame determined for a constant velocity of the rotary drive as well as a second velocity profile of the support structure with respect to the frame determined for an adjusted velocity of the rotary drive;

Fig. 5 shows a block diagram of a method for adjusting the driving velocity of the crank of the slider-crank mechanism by means of a driving velocity controller, in order to realize the improved velocity profiles of the support structure with respect to the frame shown in Fig. 4; and

Fig. 6 shows a method for adjusting the revolution operation of the crank of the slider-crank mechanism based on signals received from at least one sensor.

[0041] Fig. 1 shows an embodiment of a four-bar linkage 4 of a rocking bed 1 according to the invention. The four-bar linkage 4 comprises a frame 5 with two cranks 6 pivotably mounted on the frame 5 via a first pivot P1 and a second pivot P2. A movable linkage 7 is pivotably connected to the cranks 7 via a third pivot P3 and a fourth pivot P4. Together with the cranks 6, the movable linkage 7 is configured to guide a movement of a support structure 8 relative to the frame 5, wherein the support structure 8 is connected to the movable linkage 7 via a fifth pivot P5. The support structure 8 is preferably configured such that a person may lay down on or such that a cushioning structure such as mattress may be arranged on the support structure 8, wherein the person may lay down on the cushioning structure.

[0042] The four-bar linkage 4 allows to guide a movement of the fifth pivot P5, and thus of the support structure 8 connected to the fifth pivot P5, with respect to the frame 5, wherein the support structure is driven by means of a slider-crank mechanism 2, as shown in Fig. 2. To illustrate the relative movement between the frame 5 and the support structure 8, Fig. 1 depicts in rigid lines a first position and in dashed lines a second position of the cranks 6, the movable linkage 7 and the support structure 8. In the first position, the two cranks 6, the third pivot P3, the fourth pivot P4 and the fifth pivot P5 as well as the support structure 8 are displaced with respect to the second position. In contrast, the first pivot P1 and the second pivot P2 are not displaced between the first and the second position, as they are arranged on the frame 5.

[0043] The movable linkage 7 according to this embodiment forms a rigid triangle with its three sides connecting the third pivot P3, the fourth pivot P4 and the fifth pivot P5. Consequently, the four-bar linkage 4 allows to realize an essentially horizontal movement of the fifth pivot P5 and thus the support structure 8, as the four-bar linkage 4 acts as a Roberts linkage. The horizontal direction is indicated as the x-direction in Fig. 1.

[0044] In this example embodiment, the distance l_1

between the first pivot P1 and the third pivot P3 as well as between the second pivot P2 and the fourth pivot P4 is $l_1 = 366.7$ mm, the distance between the third pivot P3 and the fourth pivot P4 is $l_2 = 260$ mm; the distance l_3 between the third pivot P3 and the fifth pivot P5 and between the fourth pivot P4 and the fifth pivot P5 is $l_3 = 288.9$ mm and the distance l_4 between the first pivot P1 and the second pivot P2 is $l_4 = 781.1$ mm. For these distances between the different pivots, the four-bar linkage 4 allows to guide the support structure 8 back and forth in an almost perfectly horizontally manner along and against the x-direction indicated by the coordinate system in Fig. 1, realizing a rocking motion of the support structure 8 with respect to the frame 5. The movement merely comprises a vertical component along the vertical direction perpendicularly to the horizontal direction, corresponding to the y-direction indicated in Fig. 1, of 0.0001 mm. The resulting, essentially horizontal movement is perceived as comfortable by a person resting on the support structure 8 and in particular allows to efficiently treat sleep-related disorders.

[0045] Fig. 2 shows an embodiment of a rocking bed 1 according to the invention. This side view of the rocking bed 1 illustrates the mechanical connection between the frame 5 and the support structure 8 of the rocking bed 1 formed by the four-bar linkage 4. Fig. 2 also shows a slider-crank mechanism 2 for moving the support structure 8 with respect to the frame 5. To this end, the slider-crank mechanism 2 comprises a rotary drive 3 with a control unit configured to realize a revolution operation of a crank 22 of the slider-crank mechanism 2. The rotation of the crank 22 of the slider-crank mechanism 2 can be converted into said horizontal movement between the support structure 8 and the frame 5 via a connecting rod 21 of the slider-crank mechanism 2, which mechanically connects the crank 22 and the support structure 8. In this embodiment, the mechanical connection between the connecting rod 21 and the support structure 8 is realized by a sixth pivot P6 and a connecting section 10, wherein the sixth pivot P6 forms a pivotable connection between the connecting rod 21 and the support structure 8 via the connecting section 10. As such, the support structure 8 may be moved back and forth with respect to the frame 5 under continuous rotation of the crank 22 with multiple revolutions with the same sense of the crank 22 around a rotation axis A1 of the slider crank mechanism 2. Consequently, stick-slip effects related to repeated onsets of movements of the slider-crank mechanism 2, which occur particularly for rotary drives 3 that repeatedly change the sense of the rotation of the crank 22 are avoided, which results in a particularly smooth movement of the support structure 8 with respect to the frame 5.

[0046] The amplitude of the movement between the support structure 8 and the frame 5, that is, the maximum relative displacement between the support structure 8 and the frame 5 during one revolution of the crank 22 of the slider-crank mechanism 2, depends on the distance between the crank 22 and a rotation axis A1 of the slider-

crank mechanism 2. For example, the amplitude is 100 mm, wherein the movement happens essentially in a horizontal plane, particularly for the distances between the pivots of the four-bar linkage 4 disclosed in the context of Fig. 1 above.

[0047] As can further be seen in Fig 2., the slider-crank mechanism 2 is fastened to the frame 5 via multiple dampers 11 configured to damp vibrations caused by the rotary drive 3, and the connecting rod 21 extends beyond the sixth pivot P6 with a portion that comprises a counterweight 23. The counterweight 23 allows to generate a torque equilibrium around the sixth pivot P6, which mitigates the effect of the mass of the connecting rod 21 on the horizontal movement of the support structure 8. These measures further improve the smoothness of the movement of the support structure 8 with respect to the frame 5.

[0048] Fig. 3 shows an embodiment of the crank 22 of the slider-crank mechanism 2 according to the invention, wherein the crank 22 is formed as a flywheel 24. The flywheel 24 is configured to be set into revolution operation by said rotary drive 3 and comprises a plurality of receptacles 9 by means of holes arranged in a spiral shape around the rotation axis A1 of the slider-crank mechanism 2, such that the receptacles 9 comprise different distances to the rotation axis A1. According to this embodiment, the connecting rod 21 can be pivotably attached selectively at different receptacles 9, and thus, in different distances to the rotation axis A1 of the crank 22, which allows to adjust the amplitude of the movement between the support structure 8 and the frame 5.

[0049] Fig. 4 shows a first velocity profile of the support structure 8 with respect to the frame 5 determined for a constant velocity of the rotary drive 3 as well as a second velocity profile of the support structure 8 with respect to the frame 5 determined for an adjusted velocity of the rotary drive 3, wherein each velocity profile is determined during one revolution of the crank 22 of the slider-crank mechanism 2. As can be seen from comparing the two velocity profiles, the first velocity profile comprises deviations from a perfectly sinusoidal movement, which is caused by the finite length of the connecting rod 21 between the crank 22 of the slider-crank mechanism 2 and the sixth pivot P6, cf. Fig. 2. Additionally, mechanical vibrations caused by the rotary drive 3 and transmitted to the support structure 8 via the four-bar linkage 4 typically lead to further deviations from a perfectly sinusoidal movement. In an embodiment, the control unit is configured to adjust the driving velocity of the crank 22 of the slider-crank mechanism 2 based on the first velocity profile determined for a constant driving velocity of the crank 22 during at least one revolution of the crank 22 around its rotation axis A1, such that for the adjusted driving velocity, the support structure 8 exhibits the second velocity profile, wherein the second velocity profile comprises less deviations from a sinusoidal velocity profile than the first velocity profile, corresponding to a more smooth movement of the support structure 8 with respect

to the frame 5 compared to the case of a constant velocity of the crank 22. The resulting second velocity profile can be essentially sinusoidal, as shown in Fig. 4.

[0050] Fig. 5 depicts a method for adjusting the driving velocity of the crank 22 by means of a driving velocity controller 33 for the rotary drive 3, in order to realize the improved velocity profiles of the support structure 8 with respect to the frame 5 shown in Fig. 4.

[0051] According to the method, a Proportional Integral (PI) controller 30 is combined with a Learning Feedforward (LFF) controller 31. The PI controller 30, the LFF controller 31 as well as the driving velocity controller 33 may be comprised by the control unit.

[0052] To improve the velocity profiles toward a predetermined reference profile, for example a sinusoidal profile, a driving velocity controller 33 may initially cause the rotary drive 3 to rotate at a predetermined driving velocity, for example a constant driving velocity.

[0053] The supporting structure 8 is then moved back and forth with respect to the frame 5 according to the driving velocity of the rotary drive 3. As pointed out above particularly for the case of a constant driving velocity, the resulting movement of the support structure 8 with respect to the frame 5 typically comprises deviations from a perfectly sinusoidal shape during one revolution of the crank 22 of the slider crank mechanism 2, due to the finite length of the connecting rod 21 and mechanical vibrations caused by the rotary drive 3.

[0054] The actual velocity profiles of the support structure 8 are measured using sensors and particularly averaged over multiple revolutions of the crank 22, before being filtered by a filter 32, particularly using a cascaded 4th order Butterworth filter with cut-off frequency at 30 Hz and a 5th order mean filter.

[0055] The filtered actual velocity profile is compared to the reference velocity profile by the PI controller 30 with an anti-windup method implemented to prevent an overshooting of the velocity when the rotary drive 3 saturates. Saturation of the rotary drive 3 typically occurs when the output of the driving velocity controller 33 to the rotary drive 3 exceeds the physical limit of the rotary drive 3. In this case, the desired motion can no longer be realized, and as a result, large overshoots and sustained oscillation may develop. The anti-windup method limits the value of the integral. The integral part is less sensitive to noise than the derivative part, yet still allows acceptable tracking behavior.

[0056] Based on the comparison between the actual and the reference velocity profile, the PI controller 30 provides torque setpoint to the driving velocity controller 33 which corresponds to an adjusted driving velocity for the rotary drive 3.

[0057] Moreover, the driving velocity controller 33 receives an input from the LFF controller 31 in order to determine optimized torques of the rotary drive 3 to be provided for different rotational angles of the flywheel 24 around the rotation axis A1 in order to realize a good tracking performance and to counteract repeating dis-

turbances due to vibrations caused by the rotary drive 3 and the mechanical connections between the frame 5 and the supporting structure 8. At the same time, the LFF controller 31 is configured to account for a dependence of the torque of the rotary drive 3 on the rotational angle of the flywheel 24 by means of a learning algorithm which allows for prediction of the torque as a function of the rotational angle. LFF controller 31 was realized with a second order, single layer B-spline neural network. The B-splines are pre-computed for uniformly distributed angles in the range of 0 to 2π and stored in a lookup table with 500 entries.

[0058] The torque setpoint of the driving velocity controller 33 may be limited, particularly limited below the saturation of the rotary drive 3 for safety reasons. This may be done to avoid prematurely hitting the saturation of the rotary drive 3 when optimizing the velocity profiles and should be readjusted for an effective anti-windup implementation. This limit can result in higher torques provided by the rotary drive 3 for a short time duration than the torque setpoint of the driving velocity controller 33 would allow for.

[0059] Particularly, the driving velocity controller 33 may comprise a safety mechanism or algorithm configured such that it causes the rotary drive 3 to stop upon a failure event. For example, a failure event may be detected by means of the recorded actual velocity profiles, particularly in case the recorded actual velocity profiles comprise features exceeding predetermined deviation limits.

[0060] Fig. 6 shows a method for adjusting the revolution operation of the crank 22 of the slider-crank mechanism 2 based on signals received from at least one sensor 12 arranged on or near the rocking bed 1. For example, the sensor 12 may be configured to record movements, electromagnetic radiation and/or sounds while the support structure 8 of the rocking bed 1 is moved relative to the frame 4. The sensor may also be configured to record at least one of the following: brain activity, particularly EEG; oxygen saturation, particularly SpO₂; heart activity, particularly ECG or BCG; nasal flow or textile, radar signals. In case the sensor 12 is configured to record movements, it is preferably mounted on the support structure 8 or on a mattress on the support structure, such that the movements of the support structure 8 with respect to the frame 5 may be detected.

[0061] The sensor 12 is configured to generate sensor signals 13 indicative of the movements, electromagnetic radiation and/or sounds recorded by the at least one sensor 12. Particularly, the sensor signals 13 comprise actions of a person 17 or a patient resting, particularly sleeping on the support structure 8, such as recorded movements or recorded sounds such as snoring.

[0062] The sensor signals 13 are implemented into an algorithm 14, particularly a neuronal network or a classification algorithm, to extract physiological parameters 15 representing a physiological state of the person 17, based on the sensor signals 13.

[0063] The physiological parameters 15 are considered by an intervention algorithm 16 aiming at adjusting the revolution operation of the crank 22 to influence the physiological parameters 15 and thus the physiological state of the person 17.

[0064] As shown in Fig. 6, the above process may be executed repeatedly in a loop, in order to test the effect of the adjustments of the revolution operation of the crank 22 on the physiological state of the person 17.

List of reference signs

[0065]

Rocking bed	1	15
Slider-crank mechanism	2	
Rotary drive	3	
Four-bar linkage	4	
Frame	5	20
Crank	6	
Movable linkage	7	
Support structure	8	
Receptacle	9	
Connecting section	10	25
Damper	11	
Sensor	12	
Sensor signals	13	
Algorithm	14	30
Physiological parameters	15	
Intervention algorithm	16	
Person	17	
Connecting rod of slider-crank mechanism	21	
Crank of slider-crank mechanism	22	35
Counterweight	23	
Flywheel	24	
PI controller	30	
LFF controller	31	40
Filter	32	
Driving velocity controller	33	
Rotation axis	A1	
First pivot	P1	
Second pivot	P2	45
Third pivot	P3	
Fourth pivot	P4	
Fifth pivot	P5	
Sixth pivot	P6	50

Claims

1. A rocking bed (1), comprising:

- a slider-crank mechanism (2) comprising a rotary drive (3) and

- at least one four-bar linkage (4) comprising a frame (5) with two cranks (6) pivotably mounted thereon via a first pivot (P1) and a second pivot (P2), and a movable linkage (7) pivotably connected to the cranks (6) via a third pivot (P3) and a fourth pivot (P4),

wherein a connecting rod (21) of the slider-crank mechanism (2) is pivotably connected to a support structure (8) of the rocking bed (1) via a sixth pivot (P6), wherein there is a pivotable connection between the movable linkage (7) and the support structure (8) of the rocking bed (1) via a fifth pivot (P5), via which a movement of the support structure (8) can be guided along a horizontal direction and wherein the rotary drive (3) has a control unit configured to realize a revolution operation of a crank (22) of the slider-crank mechanism (2).

2. The rocking bed (1) according to claim 1, wherein the fifth pivot (P5) is arranged outside an imaginary linear connection of the third pivot (P3) and the fourth pivot (P4).

3. The rocking bed (1) according to one of the claims 1 or 2, wherein the fifth pivot (P5) and the first and the second pivot (P1, P2) are arranged between two imaginary horizontal planes comprising a spacing of Δy , wherein Δy is smaller than, a distance l_1 between the first pivot (P1) and the third pivot (P3) and/or between the second pivot (P2) and the fourth pivot (P4).

4. The rocking bed (1) according to one of the preceding claims, wherein:

- a distance between the third pivot (P3) and the fourth pivot (P4) is l_2 , with l_1/l_2 being between 1.2206 and 2.5467,
- a distance between the third pivot (P3) and the fifth pivot (P5) and a distance between the fourth pivot (P4) and the fifth pivot (P5) is l_3 , with l_1/l_3 being between 1.0015 and 1.9291 and/or
- a distance between the first pivot (P1) and the second pivot (P2) is l_4 , with l_1/l_4 being between 0.4568 and 0.8444.

5. The rocking bed (1) according to one of the claims 3 or 4, wherein the fifth pivot (P5) is arranged on a first side of an axis extending through the first pivot (P1) and the second pivot (P2) and wherein the third pivot (P3) and the fourth pivot (P4) are arranged on a second side of said axis opposite to the first side.

7. The rocking bed (1) according to one of the preceding claims, wherein the crank (22) of the slider-crank mechanism (2) comprises a plurality of receptacles (9) for receiving the connecting rod (21), wherein the receptacles are arranged at different radial distances to the rotation axis of the crank (22) of the slider-crank mechanism (2), such that a radial distance between the rotation axis of the crank (22) and a pivot connection connecting the connecting rod (21) and the crank (22) of the slider-crank mechanism (2) and thus a maximum deflection amplitude of the relative movement between the support structure (8) and the frame (5) can be changed. 5 10
8. The rocking bed (1) according to one of the preceding claims, wherein the crank (22) of the slider-crank mechanism (2) is formed by and acts as a flywheel (24). 15
9. The rocking bed (1) according to one of the preceding claims, wherein the connecting rod (21) of the slider-crank mechanism (2) extends beyond the sixth pivot (P6) with a portion that comprises a counterweight (23) 20 25
10. The rocking bed (1) according to one of the preceding claims, comprising at least three four-bar linkages (4) wherein the plurality of four-bar linkages (4) is arranged on the same frame (5). 30
11. The rocking bed (1) according to one of the preceding claims, wherein the control unit is configured to adjust a driving velocity of the crank (22) of the slider-crank mechanism (2) based on a first velocity profile of the movement of the support structure (8) with respect to the frame (5) determined for a constant driving velocity of the crank (22) of the slider-crank mechanism (2) during at least one revolution of the crank (22) around the rotation axis (A1) of the slider-crank mechanism (2), such that for an adjusted driving velocity, the support structure (8) exhibits a second velocity profile, wherein the second velocity profile comprises less deviations from a sinusoidal velocity profile than the first velocity profile. 35 40 45
12. The rocking bed (1) according to one of the preceding claims, comprising at least one sensor (12), wherein the sensor (12) is configured to record movements, electromagnetic signals, electromagnetic radiation and/or sounds and to generate sensor signals (13) indicative of the movements, the electromagnetic signals, the electromagnetic radiation and/or the sounds and to send the sensor signals (13) to the control unit. 50 55
13. The rocking bed (1) according to claim 12, wherein the control unit is configured to adjust the revolution operation of the crank (22) of the slider-crank mechanism (2) based on the sensor signals (13) received from the at least one sensor (12).
14. A method for operating a rocking bed (1) according to one of the claims 1 to 13, wherein the control unit causes the rotary drive (3) of the slider-crank mechanism (2) to realize a revolution operation of the crank of the slider-crank mechanism (2) around a rotation axis of the slider-crank mechanism (2), such that the support structure (8) is moved back and forth relative to the frame (5) by means of forces transmitted from the connecting rod (21) of the slider-crank mechanism (2) to the support structure (8).
15. A computer program for operating a rocking bed (1), comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method of claim 14.

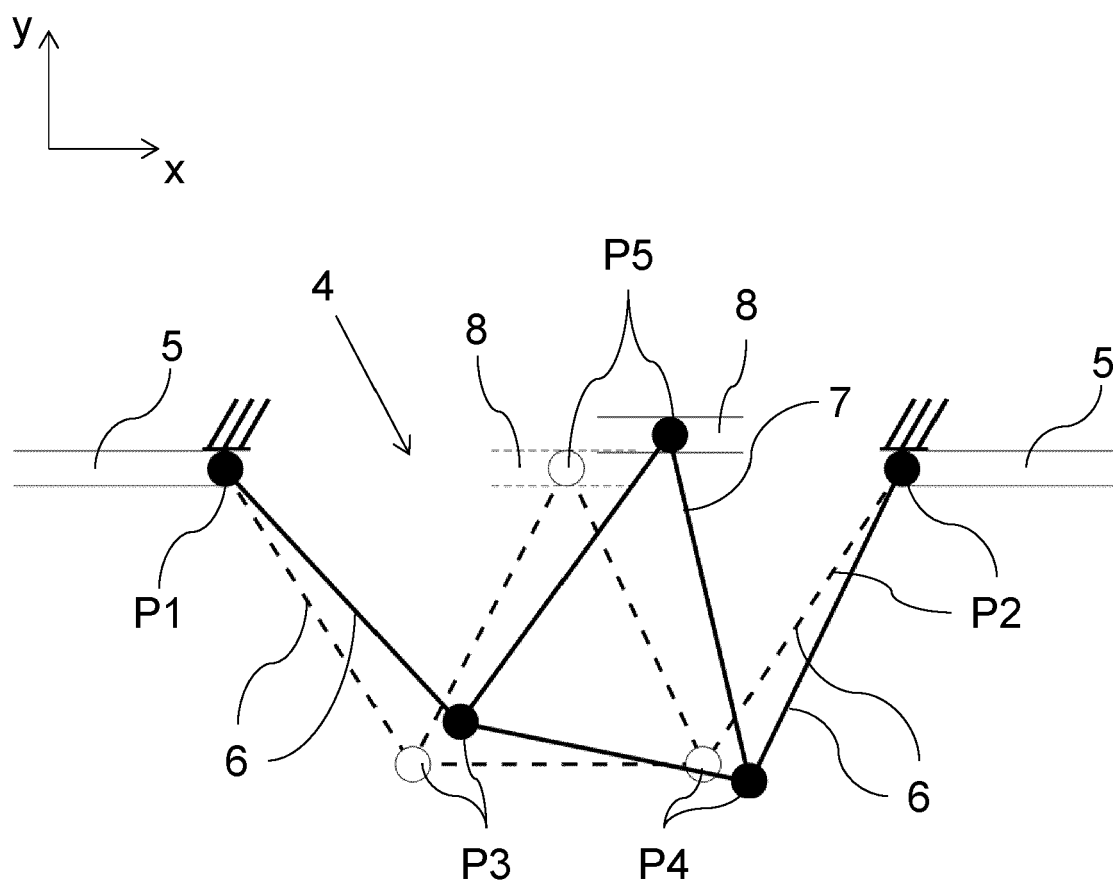


Fig. 1

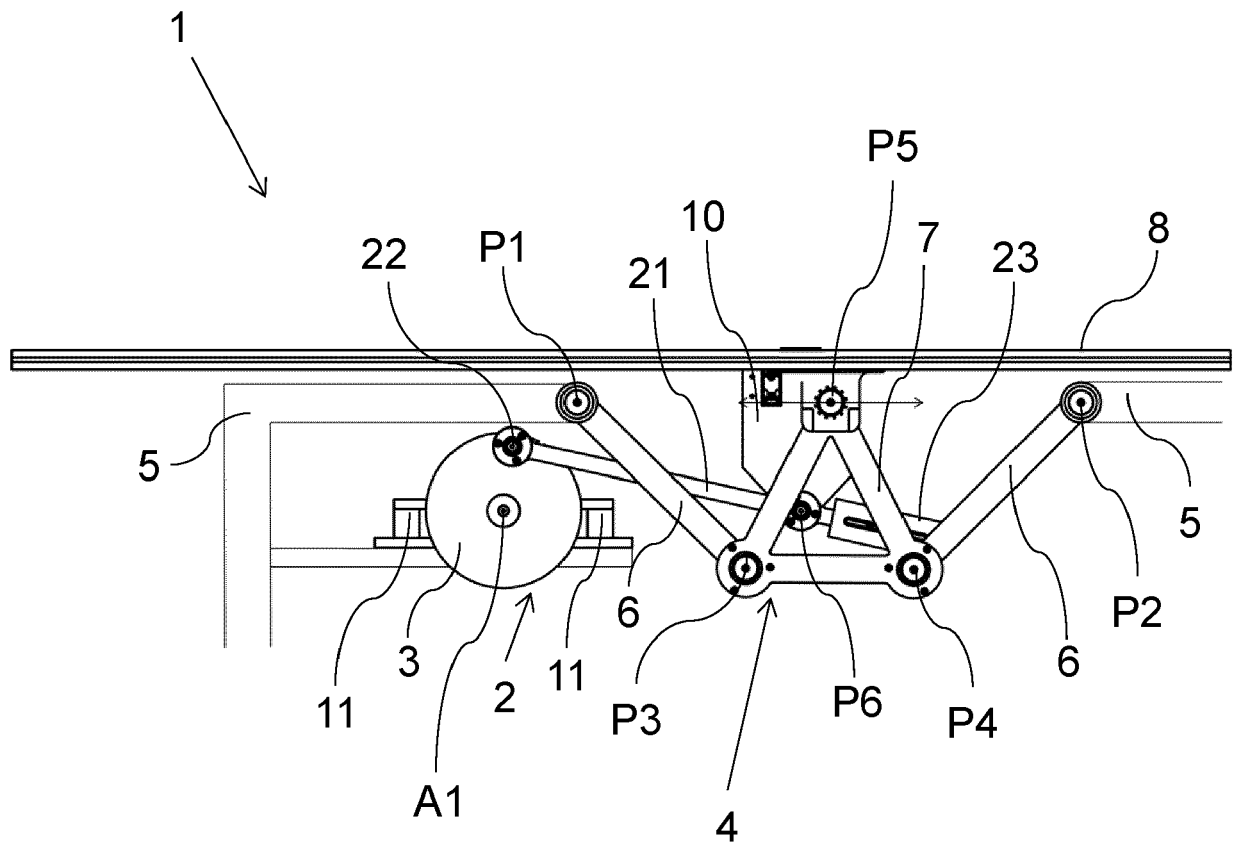


Fig. 2

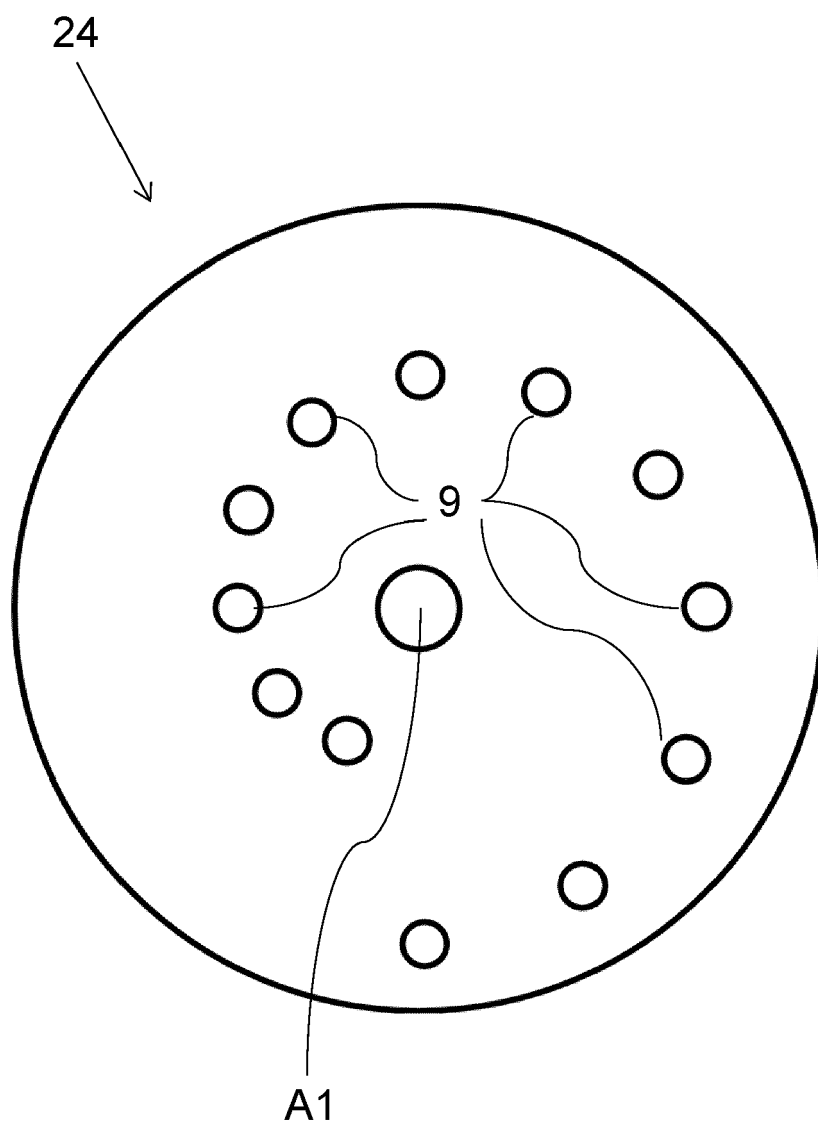


Fig. 3

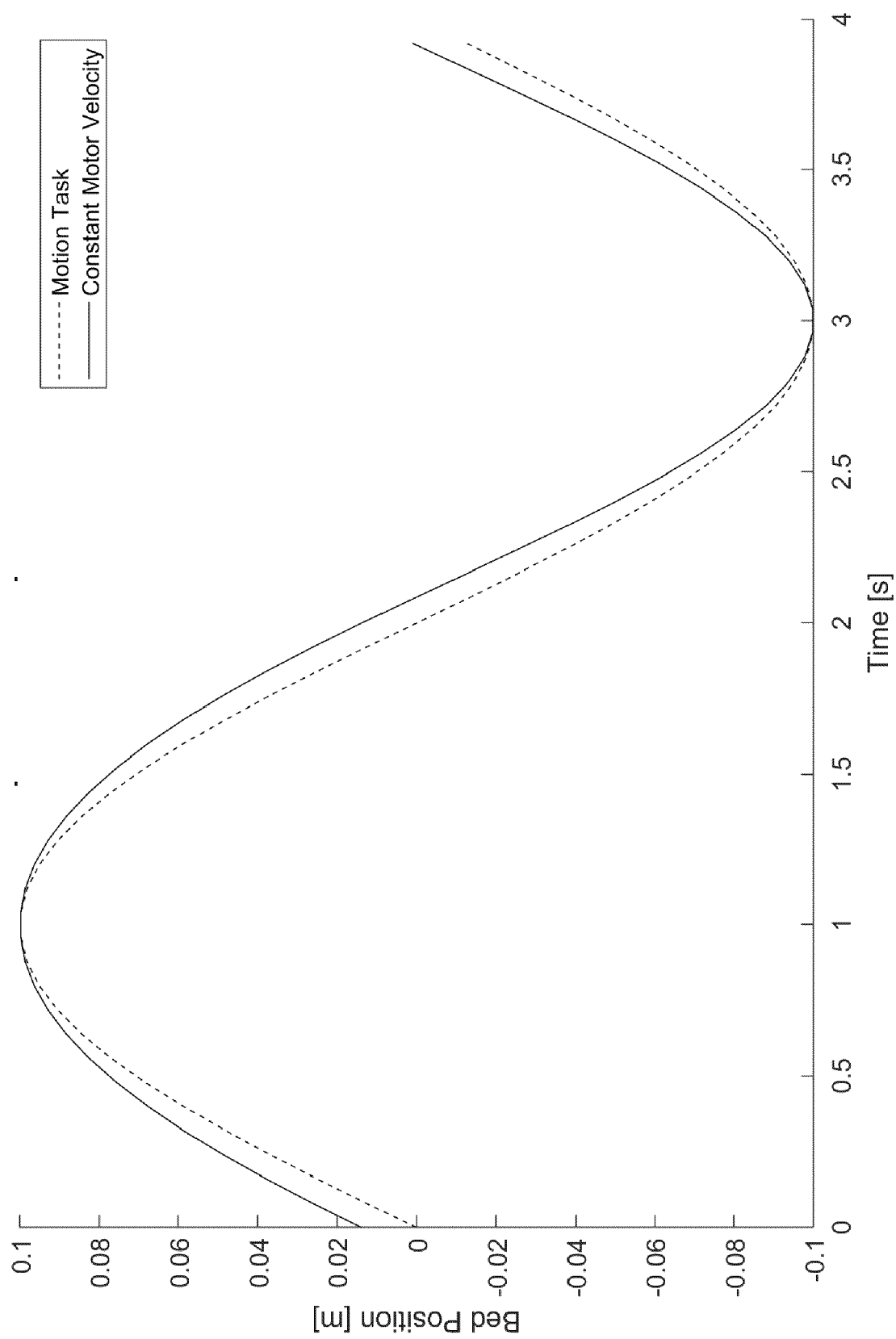


Fig. 4

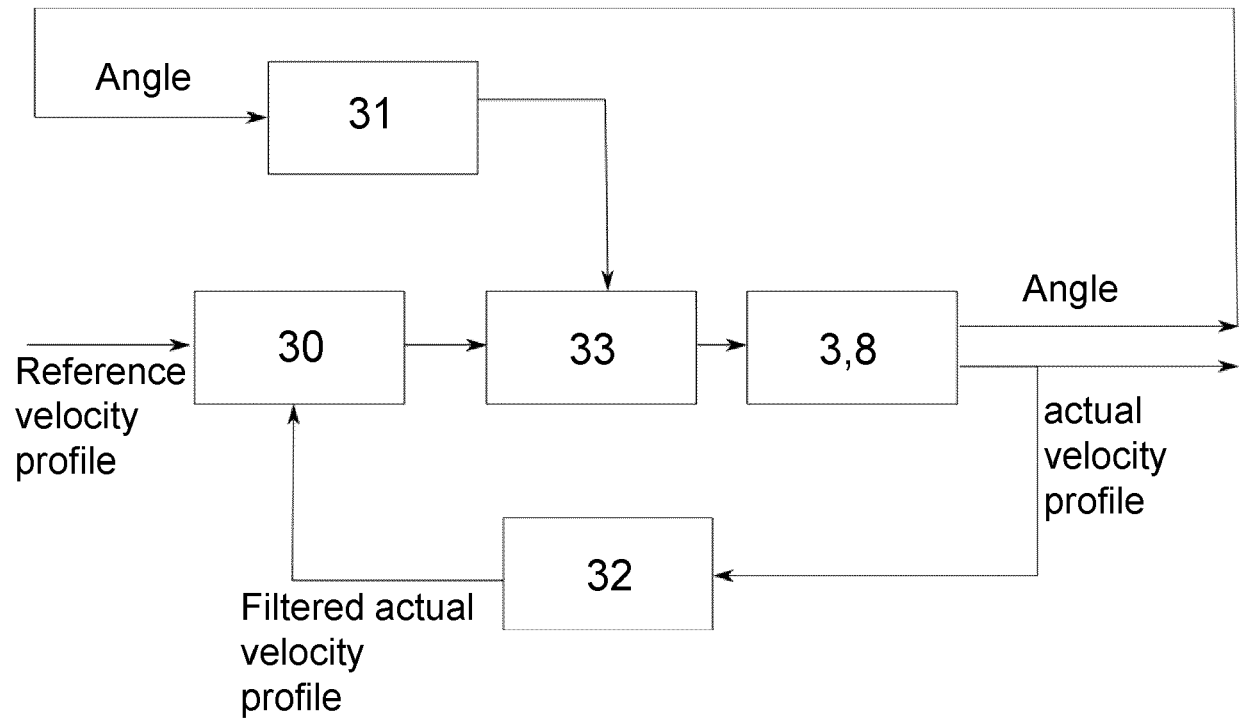


Fig. 5

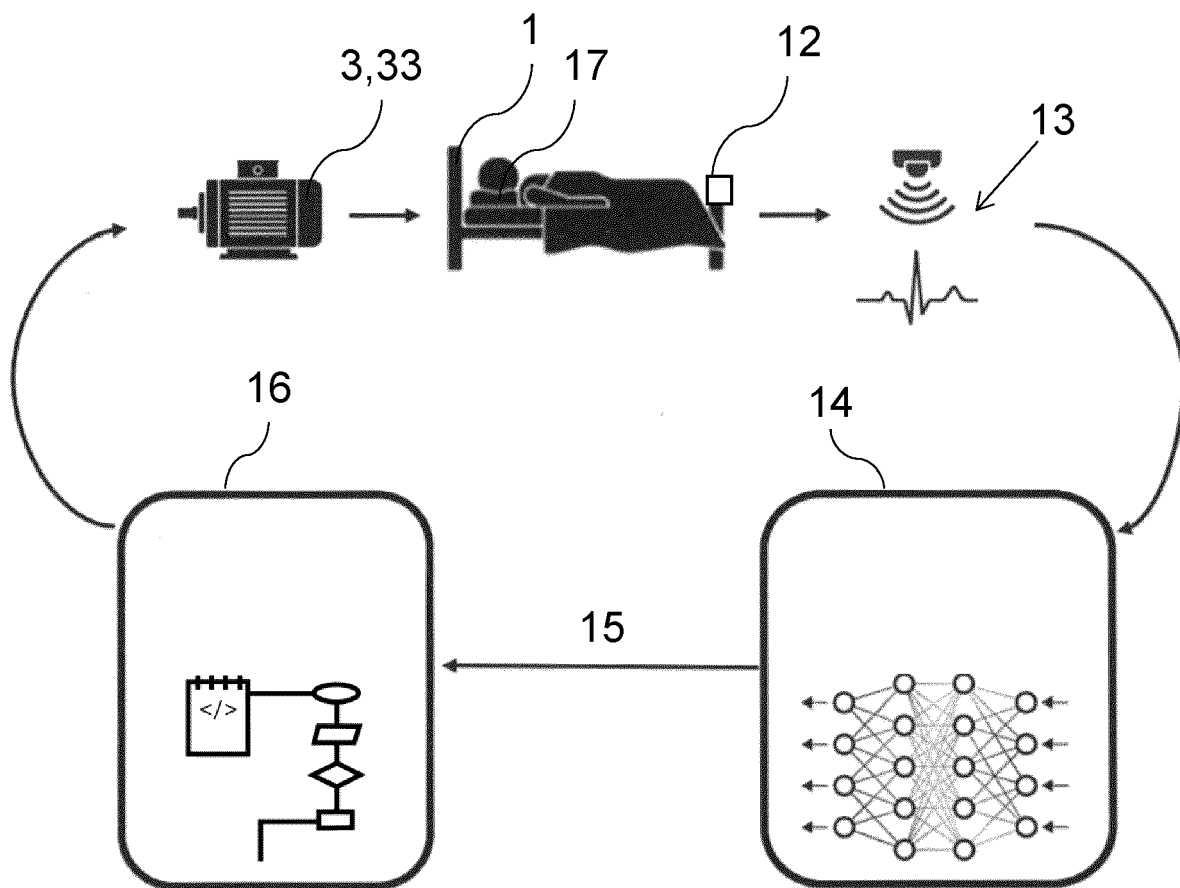


Fig. 6



EUROPEAN SEARCH REPORT

Application Number

EP 23 19 0463

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2016/183619 A1 (CHAPMAN GREGORY ALLAN [AU]) 24 November 2016 (2016-11-24)	1, 2, 6, 8, 10, 11, 14, 15	INV. A47C21/00
A	* paragraph [0041]; figures 1, 2, 6 * -----	3-5, 7, 9, 12, 13	
			TECHNICAL FIELDS SEARCHED (IPC)
			A47C A47D A61H
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		8 January 2024	Ibarrondo, Borja
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
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08-01-2024

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