

DESCRIPTION

TITLE

TRANSPORTATION AID DEVICE

5

TECHNICAL FIELD

[0001]

The present disclosure relates to a transport assistance apparatus.

10 BACKGROUND ART

[0002]

For example, Patent Document 1 discloses an auxiliary propulsion system using mecanum wheels in a drive unit. The auxiliary propulsion system includes a pair of mecanum wheels connected to a chassis, motors that respectively drive the mecanum wheels, and a control system that senses changes in the rotational speed of each motor.

15

[0003]

According to Patent Document 1 described above, when moving the chassis in a predetermined direction, the operator applies a force in the same direction. As each mecanum wheel is rotated by the applied force, an associated change in rotational speed is reported to the control system. The control system starts electric rotation of the motors based on the report. The electric rotation assists the movement of the chassis.

20

CITATION LIST

PATENT DOCUMENT

25 [0004]

SUMMARY OF THE INVENTION

TECHNICAL PROBLEM

5 [0005]

As an example, a situation where a bed with casters to which the configuration described in Patent Document 1 is applied turns a corner is considered. In this case, the bed is pushed to the front or the back while turning, and thus, assisting the movement of the bed in the front-rear direction is required.

10 [0006]

As a result of intensive studies, the inventors of the present application have found that the turning radius of the bed is excessively small when the movement of the bed is simply assisted in the front-rear direction during the turn, and the front or rear end of the bed may interfere with a corner of a passage such as a crossroad or a T-junction. Such interference is disadvantageous in assisting the turn of the bed.

[0007]

The present disclosure has been made in view of the above circumstances, and an object thereof is to suitably assist the turn of a bed with casters.

20 SOLUTION TO THE PROBLEM

[0008]

A first aspect of the present disclosure relates to a transport assistance apparatus for assisting a hand-propelled movement of a bed with casters. The transport assistance apparatus includes: a first mecanum wheel and a second mecanum wheel that are attached to a lower portion of the bed and make contact with a transport surface on which the bed travels; a first

motor and a second motor that are respectively connected to the first mecanum wheel and the second mecanum wheel to drive the first mecanum wheel and the second mecanum wheel; a status sensor that detects signals corresponding to rotation statuses of the first and second mecanum wheels; a turning sensor that detects a turn of the bed about a rotation axis perpendicular to the transport surface; and a controller that controls the first and second motors. The controller determines whether the bed is moving forward or rearward and whether the bed is turning based on detection signals of the status sensor and the turning sensor. The controller drives the first and second mecanum wheels via the first and second motors to assist the hand-propelled movement in a front-rear direction when it is determined that the bed is moving forward or rearward without turning, and drives the first and second mecanum wheels via the first and second motors to assist the hand-propelled movement in both the front-rear direction and a lateral direction perpendicular to the front-rear direction and parallel to the transport surface when it is determined that the bed is turning while moving forward or rearward.

[0009]

According to the first aspect, the controller assists the hand-propelled movement of the bed in the front-rear direction and the lateral direction as well. When the bed turns a corner, it is considered that a force is also applied in a turning radius direction, that is, in the lateral direction of the bed. Assisting such a lateral force allows the bed to slide in the lateral direction when turning the corner. As a result, the turning radius increases, reducing the interference between the front or rear end of the bed and the corner of the passage. This can suitably assist the bed with casters in turning the corner.

[0010]

According to a second aspect of the present disclosure, the status sensor may include a first current sensor that detects an induced current flowing through the first motor when the first mecanum wheel rotates, and a second current sensor that detects an induced current

flowing through the second motor when the second mecanum wheel rotates. The controller may estimate a longitudinal acceleration indicating an acceleration of the first and second mecanum wheels in the front-rear direction and a lateral acceleration indicating an acceleration of the first and second mecanum wheels in the lateral direction based on the detection signals of the first and second current sensors, and may perform first control of commanding rotational speeds of the first and second motors based on at least one of the longitudinal acceleration or the lateral acceleration to follow the hand-propelled movement. When it is determined that the bed is turning while moving forward or rearward, the controller may perform the first control for the front-rear direction based on the longitudinal acceleration, and may perform the first control for the lateral direction based on the lateral acceleration after being adjusted to decrease by a predetermined ratio exceeding zero.

[0011]

According to the second aspect, detecting the induced current allows estimating torque that causes the induced current (the torque that causes the mecanum wheel to rotate), and thus, allows estimating the acceleration corresponding to the torque. Estimating the acceleration of each wheel allows estimating the direction in which the external force acts.

[0012]

Then, while the assistance is provided in the front-rear direction to follow the hand-propelled movement, the acceleration in the lateral direction is reduced, and the first control is performed based on the reduced acceleration. Reducing the acceleration in the lateral direction is equivalent to estimating the external force acting in the same direction to be smaller than the external force actually acting. By estimating the external force to be small, assistance in the lateral direction is given to the extent not to follow the hand-propelled movement. As a result, excessive sliding in the lateral direction (sliding more than intended by the transporter) can be reduced, and the turning radius can be kept within an appropriate range. This is advantageous

in suitably assisting the bed with casters in turning the corner.

[0013]

According to a third aspect of the present disclosure, the predetermined ratio may be set so that a turning center of the bed is shifted from a center position between the first and second mecanum wheels to a front end of the bed.

[0014]

According to the third aspect, the turning center of the bed is shifted to the front end, allowing the rear end of the bed to turn more than the front end when the bed turns the corner. By greatly turning the rear end, interference between the rear end and the corner of the passage can be reduced. This is advantageous in suitably assisting the bed with casters in turning the corner.

[0015]

According to a fourth aspect of the present disclosure, when it is determined that the bed is moving forward or rearward without turning, the controller may perform the first control based on the longitudinal acceleration and second control of increasing the commanded rotational speeds. When it is determined that the bed is turning while moving forward or rearward, the controller may perform the first control and the second control in order for the front-rear direction based on the longitudinal acceleration, and may perform the first control for the lateral direction based on the adjusted lateral acceleration without performing the second control.

[0016]

According to the fourth aspect, the second control performed for the front-rear direction allows the wheels not only to simply follow the hand-propelled movement, but also reduces the load on the transporter by the amount of increase in the commanded rotational speeds. This makes it easier to push the bed in the front-rear direction, and can give the

transporter an appropriate “feeling of being assisted.” For the lateral direction, the second control is intentionally omitted. This can reduce excessive sliding of the bed in the lateral direction (sliding more than intended by the transporter), and can keep the turning radius within an appropriate range. This is advantageous in suitably assisting the bed with casters in turning the corner.

[0017]

According to a fifth aspect of the present disclosure, the first and second mecanum wheels may be arranged side by side in the lateral direction, each of the first and second mecanum wheels may include a wheel body that rotates about a rotation axis extending in the lateral direction, and a plurality of barrel-shaped rollers that are arranged along an outer periphery of the wheel body and rotate about an inclined axis inclined with respect to both the front-rear direction and the lateral direction, and the inclined axis of the first mecanum wheel may be inclined to be line-symmetrical with the inclined axis of the second mecanum wheel with respect to the front-rear direction.

[0018]

With the configuration according to the fifth aspect, a thrust that causes the bed to turn can be exerted when the first mecanum wheel and the second mecanum wheel rotate in opposite directions. This configuration is effective in appropriately assisting the bed with casters in turning the corner.

[0019]

According to a sixth aspect of the present disclosure, the controller may command rotational speeds of the first and second mecanum wheels so that both the first and second mecanum wheels rotate forward or rearward when it is determined that the bed is moving forward or rearward without turning, and when commanding the rotational speeds, may make absolute values of the commanded rotational speeds of the first and second mecanum wheels

equal to each other, and may command the rotational speeds so that the first mecanum wheel and the second mecanum wheel have different absolute values when it is determined that the bed is turning while moving forward or rearward.

[0020]

5 According to the sixth aspect, the absolute values of the commanded rotational speeds are made equal to each other for the front-rear movement, allowing more stable front-rear movement regardless of the orientation of the casters. When the bed turns the corner, the absolute values are intentionally made different from each other, allowing the bed to turn along a desired trajectory.

10

ADVANTAGES OF THE INVENTION

[0021]

As described above, the present disclosure can suitably assist the bed with casters in turning the corner.

15

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

[FIG. 1] FIG. 1 is a side view illustrating a general configuration of a transport assistance apparatus and a bed with casters.

20

[FIG. 2] FIG. 2 is a bottom view illustrating the general configuration of the transport assistance apparatus and the bed with casters.

[FIG. 3] FIG. 3 is a perspective view illustrating the configuration of the transport assistance apparatus.

[FIG. 4] FIG. 4 is a plan view illustrating the configuration of the transport assistance
25 apparatus.

[FIG. 5] FIG. 5 is a side view illustrating the configuration of the transport assistance apparatus.

[FIG. 6] FIG. 6 is a block diagram illustrating a configuration of a control system of the transport assistance apparatus.

5 [FIG. 7] FIG. 7 is a view illustrating how first and second mecanum wheels move.

[FIG. 8] FIG. 8 is a view illustrating a detection target of a six-axis sensor.

[FIG. 9] FIG. 9 is a flowchart of a major process performed by a controller.

[FIG. 10] FIG. 10 is a flowchart of a process related to the determination of a moving direction.

10 [FIG. 11] FIG. 11 is a control block diagram schematically illustrating a configuration of compliance control.

[FIG. 12] FIG. 12 is a conceptual diagram illustrating a basic concept of the compliance control.

15 [FIG. 13] FIG. 13 is a graph of variation of velocity increase with respect to rotational speed.

[FIG. 14] FIG. 14 is a graph of commanded rotational speed obtained by velocity increase control.

[FIG. 15] FIG. 15 is a flowchart of the compliance control and the velocity increase control.

20 [FIG. 16] FIG. 16 is a flowchart of control related to turning a corner.

[FIG. 17] FIG. 17 is a view illustrating a trajectory of a bed when turning a corner.

[FIG. 18] FIG. 18 is a flowchart illustrating safety limit control.

[FIG. 19] FIG. 19 is a view corresponding to FIG. 17, illustrating a conventional example of the trajectory of the bed.

25

DESCRIPTION OF EMBODIMENTS

[0023]

An embodiment of the present disclosure will be described below with reference to the drawings.

5 [0024]

FIG. 1 is a side view illustrating a general configuration of a transport assistance apparatus 1 and a caster bed 10, and FIG. 2 is a bottom view illustrating the general configuration of the transport assistance apparatus 1 and the caster bed 10.

[0025]

10 FIGS. 3, 4 and 5 are perspective, plan, and side views illustrating the configuration of the transport assistance apparatus 1.

[0026]

FIG. 6 is a block diagram illustrating the configuration of a control system of the transport assistance apparatus 1, and FIG. 7 is a view illustrating how first and second mecanum wheels 21R and 21L move. FIG. 8 is a view illustrating a detection target of a six-axis sensor SW5.

[0027]

As shown in FIGS. 1 and 2, the transport assistance apparatus 1 according to the present embodiment is attached to a bed 10 with casters (hereinafter simply referred to as a
20 “bed”). The bed 10 includes a plurality of casters 14 including front casters 14F and rear casters 14B, and is used as a medical bed, for example. The transport assistance apparatus 1 is a device that assists a hand-propelled movement of the bed 10.

[0028]

Hereinafter, a lengthwise direction of the bed 10, that is, a direction in which a person
25 lies on the bed 10 is referred to as a “front-rear direction” or a “longitudinal direction,” a

direction toward the toes of the person in the front-rear direction is referred to as the “front,” and a direction toward the head of the person is referred to as the “rear.”

[0029]

Similarly, a widthwise direction of the bed 10, that is, a direction orthogonal to the front-rear direction on a horizontal plane is defined as a “left-right direction” or a “lateral direction,” a direction toward the back of the paper of FIG. 1 in the left-right direction is defined as the “right,” and a direction toward the front of the paper of FIG. 1 is defined as the “left” (see FIG. 2 for details). The “left-right direction” referred to herein means the left-right direction when the bed is viewed from the back side toward the front side. In the following description, a “lateral movement” refers to a movement in the left-right direction. The left-right direction (lateral direction) can also be defined as a direction that is orthogonal to the front-rear direction and extends along a transport surface F (a floor surface on which the bed 10 travels).

[0030]

The bed 10 is supported by a transporter 100. In the illustrated example, the bed 10 is supported at one end (e.g., a rear end) in the front-rear direction. The transport assistance apparatus 1 operates to assist the transporter 100 supporting the bed 10 to push the bed 10 by hand.

[0031]

As shown in FIG. 1, the bed 10 includes a bed body 11 on which a mattress (not shown) is placed, a frame 12 that supports the bed body 11 from below, a lifter 13 that raises and lowers the bed body 11 with respect to the frame 12, and a plurality of casters 14 (four casters in the illustrated example) arranged on the bottom of the bed 10. When used as a medical bed, the bed 10 weighs, for example, 60kg or more and 300kg or less.

[0032]

The bed body 11 includes a headboard 11h arranged at a rear end of the bed 10, a

footboard 11f arranged at a front end opposite to the rear end in the front-rear direction, and side rails 11s arranged on the left and right sides of the bed 10.

[0033]

The headboard 11h is supported from the rear side by the transporter 100 to move the bed 10 by hand. The headboard 11h serves as a support to which a force is applied by the transporter 100. A member such as a handle or a grip may be attached to or integrated with the headboard 11h so that the member is used as the support. The footboard 11f or the side rails 11s may be used as the support.

[0034]

As shown in FIG. 2, the frame 12 is formed in a rectangular frame shape, and includes four sides consisting of a front frame 12F, a right frame 12R, a left frame 12L, and a rear frame 12B.

[0035]

The front frame 12F is arranged on the front side of the bed 10 and extends in the left-right direction. The right frame 12R is arranged on the right side of the bed 10 and extends in the front-rear direction. The left frame 12L is arranged on the left side of the bed 10 and extends in the front-rear direction. The rear frame 12B is arranged on the rear side of the bed 10 and extends in the left-right direction.

[0036]

As shown in FIGS. 1 and 2, the front casters 14F and the rear casters 14B constituting the casters 14 are arranged at four corners of the bottom of the bed 10. Two front casters 14F are arranged in the left-right direction, and two rear casters 14B are also arranged in the left-right direction. The casters 14 support the frame 12, the lifter 13, and the bed body 11 with respect to the transport surface F.

[0037]

Each caster 14 is a so-called free caster, and includes a mount 14a fixed to the bottom of the bed 10, a fork 14b that can swivel about a swivel axis Oc relative to the mount 14a, and a wheel 14c rotatably supported by the fork 14b. The swivel axis Oc of each fork 14b extends vertically (along the height of the bed 10). A rotation axis of each wheel 14c extends along a horizontal plane. The rotation axis is inclined with respect to the left-right direction when the fork 14b swivels relative to the mount 14a.

[0038]

The transport assistance apparatus 1 is arranged to span a middle portion of the right frame 12R in the front-rear direction and a middle portion of the left frame L in the front-rear direction. The transport assistance apparatus 1 is arranged between the front casters 14F and the rear casters 14B in the front-rear direction and at the center of the bed 10 in the left-right direction.

[0039]

As shown in FIGS. 1 to 6, the transport assistance apparatus 1 includes a housing box 6, a fixture 7, first and second mecanum wheels 21R and 21L, first and second motors 22R and 22L, a controller 4, first and second current sensors SW1 and SW2 serving as status sensors, first and second rotation sensors SW3 and SW4, and a six-axis sensor SW5 as a turning sensor (the first and second motors 22R and 22L and the sensors SW1 to SW5 are shown only in FIG. 6). It is assumed that, of the first and second mecanum wheels 21R and 21L, the first mecanum wheel 21R is located on the right, and the second mecanum wheel 21L is located on the left.

[0040]

Among these components, the controller 4 and the six-axis sensor SW5 are contained in the housing box 6, and the fixture 7, the first and second mecanum wheels 21R and 21L, the first and second motors 22R and 22L, the first and second current sensors SW1 and SW2, and the first and second rotation sensors SW3 and SW4 are arranged outside the housing box 6.

[0041]

The housing box 6 contains the controller 4 as described above. The housing box 6 is arranged between the first mecanum wheel 21R and the second mecanum wheel 21L in the left-right direction.

5 [0042]

The housing box 6 is assembled to the fixture 7 together with the first and second mecanum wheels 21R and 21L, and is attached to the lower portion of the bed 10 with the fixture 7. The fixture 7 is detachably attached to the lower portion of the bed 10. That is, the transport assistance apparatus 1 of the present embodiment can be retrofitted to the bed 10 and can be removed as necessary.

[0043]

Specifically, as shown in FIGS. 2 to 5, the fixture 7 of the present embodiment includes a front rail member 71f, a rear rail member 71b, a first arm member 72R that rotatably supports the first mecanum wheel 21R, and a second arm member 72L that rotatably supports the second mecanum wheel 21L.

[0044]

The front rail member 71f and the rear rail member 71b are spaced in the front-rear direction, and each of the front rail member 71f and the rear rail member 71b spans a central portion of the right frame 12R in the front-rear direction and a central portion of the left frame 12L in the front-rear direction. The front rail member 71f and the rear rail member 71b are detachably attached to the right frame 12R and the left frame 12L. The first and second mecanum wheels 21R and 21L and the housing box 6 are arranged between the front rail member 71f and the rear rail member 71b in the front-rear direction.

[0045]

25 The first arm member 72R on the right side in FIGS. 3 and 4 is swingably supported

by the rear rail member 71b. A front end portion of the first arm member 72R rotatably supports the first mecanum wheel 21R. The first arm member 72R is arranged between the first mecanum wheel 21R and the housing box 6 in the left-right direction.

[0046]

5 One end of a first tension spring 75R is locked to an upper end portion of the first arm member 72R. The other end of the first tension spring 75R is locked to a first bracket 76R fixed to the front rail member 71f.

[0047]

10 The second arm member 72L on the left side in FIGS. 3 and 4 is swingably supported by the rear rail member 71b, similarly to the first arm member 72. A front end portion of the second arm member 72L rotatably supports the second mecanum wheel 21L. The second arm member 72L is arranged between the second mecanum wheel 21L and the housing box 6 in the left-right direction.

[0048]

15 One end of a second tension spring 75L is locked to an upper end portion of the second arm member 72L. The other end of the second tension spring 75L is locked to a second bracket 76L fixed to the front rail member 71f (see also FIG. 5).

[0049]

20 As shown in FIGS. 1 and 2, the first and second mecanum wheels 21R and 21L are attached to a lower portion (bottom) of the bed 10. The first and second mecanum wheels 21R and 21L are in contact with the transport surface F on which the bed 10 travels. The transport surface F is shown only in FIG. 1. The first and second mecanum wheels 21R and 21L are arranged behind the front casters 14F and in front of the rear casters 14B. In the present embodiment, the first and second mecanum wheels 21R and 21L are arranged side by side in
25 the left-right direction which is the widthwise direction, as shown in FIG. 2.

[0050]

Specifically, as shown in FIGS. 3 to 5, the first mecamum wheel 21R includes a first wheel body 211R that rotates about a first rotation axis Oy1 and a plurality of first barrel-shaped rollers 212R that are arranged along an outer periphery of the first wheel body 211R and rotate about a first inclined axis Or inclined with respect to the first rotation axis Oy1.

[0051]

The second mecamum wheel 21L includes a second wheel body 211L that rotates about a second rotation axis Oy2 and a plurality of second barrel-shaped rollers 212L that are arranged along an outer periphery of the second wheel body 211L and rotate about a second inclined axis Ol inclined in a direction different from the first inclined axis Or with respect to the second rotation axis Oy2.

[0052]

Both the first and second rotation axes Oy1 and Oy2 extend in the left-right direction. The first inclined axis Or is inclined to be line-symmetrical with the second inclined axis Ol with respect to the front-rear direction (see a symmetry axis Os shown in FIG. 4). In other words, suppose that a plane extending in the vertical direction and the front-rear direction is a mirror plane, the first inclined axis Or and the second inclined axis Ol extend to be mirror-symmetrical with respect to the mirror plane.

[0053]

When viewed from above as shown in FIG. 4 (when viewed in plan), the first and second inclined axes Or and Ol extend from the inside to the outside in the left-right direction (from the center portion in the left-right direction to the right or the left) as they extend from the rear side to the front side in the front-rear direction.

[0054]

Specifically, the first inclined axis Or extends from the center portion to the right in

the left-right direction as it extends from the rear side to the front side in the front-rear direction. The second inclined axis Ol extends from the center portion to the left in the left-right direction as it extends from the rear side to the front side in the front-rear direction.

[0055]

5 More specifically, an inclination angle θ_r of the first inclined axis Or with respect to the first rotation axis Oy1 is 45° in plan view. Similarly, an inclination angle θ_l of the second inclined axis Ol with respect to the second rotation axis Oy2 is also 45° in plan view. The direction and angle of inclination of each of the barrel-shaped rollers 212R and 212L are not limited to these examples. For example, the entire transport assistance apparatus 1 shown in
10 FIG. 2 may be rotated by a predetermined angle about a z-axis extending in the vertical direction.

[0056]

As described above, the first and second mecanum wheels 21R and 21L are mutually connected via the front rail member 71f and the rear rail member 71b shown in FIG. 3 and some other drawings. Thus, the first and second mecanum wheels 21R and 21L integrally move in
15 the front-rear direction and the left-right direction and integrally turn around a turning axis perpendicular to a horizontal plane.

[0057]

The first and second motors 22R and 22L are respectively connected to the first and second mecanum wheels 21R and 21L to drive the first and second mecanum wheels 21R and
20 21L. In particular, each of the first and second motors 22R and 22L is configured as a so-called three-phase DC brushless motor. Both the first and second motors 22R and 22L are electrically connected to the controller 4, and are controlled by the controller 4.

[0058]

A motor current corresponding to a torque load is supplied to each of the first and
25 second motors 22R and 22L to rotate them. The motor current can change the rotational speeds

of the first and second motors 22R and 22L, and can achieve switching between the forward and reverse rotations.

[0059]

The first motor 22R is connected to the first mecanum wheel 21R to be able to transmit
5 a driving force (torque) to the first mecanum wheel 21R. The second motor 22L is connected to the second mecanum wheel 21L to be able to transmit a driving force (torque) to the second mecanum wheel 21L.

[0060]

When the first motor 22R rotates, the driving force is transmitted to rotate the first
10 mecanum wheel 21R. Similarly, when the second motor 22L rotates, the driving force is transmitted to rotate the second mecanum wheel 21L.

[0061]

In the present embodiment, the forward rotation of the first motor 22R rotates the first mecanum wheel 21R forward, and the reverse rotation of the first motor 22R rotates the first
15 mecanum wheel 21R rearward. Similarly, in the present embodiment, the forward rotation of the second motor 22L rotates the second mecanum wheel 21L forward, and the reverse rotation of the second motor 22L rotates the second mecanum wheel 21L rearward.

[0062]

The first motor 22R is incorporated in the first mecanum wheel 21R, and the second
20 motor 22L is incorporated in the second mecanum wheel 21L. Incorporating the first and second motors 22R and 22L in this manner makes the entire transport assistance apparatus 1 simple and compact.

[0063]

The first and second current sensors SW1 and SW2 as the status sensors detect signals
25 corresponding to the rotation statuses of the first and second mecanum wheels 22R and 22L.

[0064]

Specifically, the first current sensor SW1 detects an induced current flowing through the first motor 22R when the first mecanum wheel 21R rotates. That is, when the first mecanum wheel 21R rotates upon receiving an external force, a rotor and stator of the first motor 22R relatively rotate, generating an induced current. The induced current detected by the first current sensor SW1 corresponds to a q-axis current.

[0065]

The magnitude of the induced current is proportional to the torque acting on the first mecanum wheel 21R when the first mecanum wheel 21R rotates upon receiving an external force. The magnitude of the torque is associated with the magnitude of the external force applied to the bed 10, and thus, with the amount of change in speed of the bed 10 due to the external force. In addition, the sign of the induced current is associated with the direction in which the first mecanum wheel 21R rotates upon receiving the external force. The sign of the induced current is opposite to the motor current that flows when the first motor 22R is driven.

[0066]

The second current sensor SW2 detects an induced current flowing through the second motor 22L when the second mecanum wheel 21L rotates. That is, when the second mecanum wheel 21L rotates upon receiving the external force, a rotor and stator of the second motor 22L relatively rotate, generating an induced current. The induced current detected by the second current sensor SW2 corresponds to a q-axis current.

[0067]

The magnitude of the induced current is proportional to the torque acting on the second mecanum wheel 21L when the second mecanum wheel 21L rotates upon receiving the external force. The magnitude of the torque is associated with the magnitude of the external force applied to the bed 10, and thus, with the amount of change in speed of the bed 10 due to the external

force. The sign of the induced current is associated with the direction in which the second mecanum wheel 21L rotates upon receiving the external force. The sign of the induced current is opposite to the motor current that flows when the second motor 22L is driven.

[0068]

5 For example, when the first mecanum wheel 21R rotates forward upon receiving the external force and the second mecanum wheel 21L rotates rearward at the same time, the first current sensor SW1 detects an induced current with the same sign as the induced current generated when the first motor 22R rotates rearward. The second current sensor SW2 detects an induced current with the same sign as the induced current generated when the second motor
10 22L rotates forward.

[0069]

As will be described in detail below, the controller 4 according to the present embodiment is configured to assist the movement in the forward direction, that is, the direction in which the external force acts, by feeding back the torque related to the induced current (more
15 specifically, by rotating the first and second motors 22R and 22L at the commanded rotational speeds corresponding to the torque).

[0070]

The first and second rotation sensors SW3 and SW4 respectively detect the rotational speeds of the first and second motors 22R and 22L. Specifically, the first and second rotation
20 sensors SW3 and SW4 according to the present embodiment are each constituted of an encoder. The first rotation sensor SW3 serving as the encoder detects the speed and angle of rotation of the first motor 22R, and the second rotation sensor SW4 also serving as the encoder detects the speed and angle of rotation of the second motor 22L.

[0071]

25 As shown in FIG. 8, the six-axis sensor SW5 as the turning sensor detects the turn of

the bed 10 about a rotation axis (z-axis in FIG. 8) perpendicular to the transport surface F. Specifically, the six-axis sensor SW5 is configured to be able to detect at least an angular velocity of a rotation angle (so-called yaw angle ψ) about a z-axis parallel to the vertical direction.

5 [0072]

More specifically, the six-axis sensor SW5 according to the present embodiment can detect, in addition to the angular velocity of the yaw angle ψ , accelerations in three directions along an x-axis extending in the front-rear direction, a y-axis extending in the left-right direction, and the z-axis extending in the vertical direction, an angular velocity of a rotation angle about
10 the x-axis (so-called roll angle ϕ), and an angular velocity of a rotation angle about the y-axis (so-called pitch angle θ). A detection signal of the six-axis sensor SW5 is inputted to the controller 4.

[0073]

The controller 4 controls the first and second motors 22R and 22L based on the
15 electrical signals inputted from the sensors SW1 to SW5. The controller 4 includes a CPU, memory, and an input/output bus, and is constituted of, for example, a control board.

[0074]

More specifically, the controller 4 commands the rotational speeds of the first and second motors 22R and 22L based on the detection signals inputted from the sensors SW1 to
20 SW5. The controller 4 inputs motor currents corresponding to the commanded rotational speeds to the first and second motors 22R and 22L. The first and second motors 22R and 22L rotate at the rotational speeds commanded by the controller 4.

[0075]

The first mecanum wheel 21R rotates at the same rotational speed as the first motor
25 22R, and the second mecanum wheel 21L rotates at the same rotational speed as the second

motor 22L. That is, setting the respective commanded rotational speeds of the first and second motors 22R and 22L is equivalent to setting the respective commanded rotational speeds of the first and second mecanum wheels 21R and 21L.

[0076]

5 By changing the signs of the commanded rotational speeds, the directions of rotation of the first motor 22R and the second motor 22L can be individually changed. By changing the rotation directions of the motors 22R and 22L, the corresponding mecanum wheels 21R and 21L can be switched between forward rotation and rearward rotation.

[0077]

10 In the present embodiment, when the first mecanum wheel 21R located on the right rotates forward, a thrust can be exerted on the transport assistance apparatus 1 and the bed 10 obliquely forward to the left (see an arrow A_{11} in FIG. 7). When the second mecanum wheel 21L located on the left rotates forward, the transport assistance apparatus 1 can exert a thrust to the bed 10 obliquely forward to the right (see an arrow A_{12} in FIG. 7).

15 [0078]

Thus, as shown in an upper left part of FIG. 7, for example, when both the first and second mecanum wheels 21R and 21L rotate forward, the thrust to the left exerted by the forward rotation of the first mecanum wheel 21R and the thrust to the right exerted by the forward rotation of the second mecanum wheel 21L cancel each other out, allowing the entire transport assistance apparatus 1 to generate a thrust to the front. This thrust can assist the bed 10 to move forward.

[0079]

Similarly, when the first mecanum wheel 21R located on the right rotates rearward, a thrust can be exerted on the transport assistance apparatus 1 and the bed 10 obliquely rearward to the right (see an arrow A_{21} in FIG. 7). When the second mecanum wheel 21L located on the

25

left rotates rearward, the transport assistance apparatus 1 can exert a thrust to the bed 10 obliquely rearward to the left (see an arrow A_{22} in FIG. 7).

[0080]

Thus, as shown in an upper right part of FIG. 7, for example, when both the first and second mecanum wheels 21R and 21L rotate rearward, the thrust to the right exerted by the rearward rotation of the first mecanum wheel 21R and the thrust to the left exerted by the rearward rotation of the second mecanum wheel 21L cancel each other out, allowing the entire transport assistance apparatus 1 to generate a thrust to the rear. This thrust can assist the bed 10 to move rearward.

[0081]

When one of the first and second mecanum wheels 21R and 21L rotates forward and the other rotates rearward, the transport assistance apparatus 1 can exert a thrust to the bed 10 in the left-right direction.

[0082]

In an example shown in a lower left part of FIG. 7, the first mecanum wheel 21R rotates rearward, and the second mecanum wheel 21L rotates forward, applying a thrust to the right to the bed 10.

[0083]

When one of the first and second mecanum wheels 21R and 21L rotates forward or rearward, the transport assistance apparatus 1 can exert a thrust to the bed 10 in an oblique direction.

[0084]

In an example shown in a lower right part of FIG. 7, the forward rotation of the second mecanum wheel 21L alone can move the bed 10 obliquely forward to the right. The forward rotation of the first mecanum wheel 21R alone can assist the bed 10 to move obliquely forward

to the left (not shown).

[0085]

The transport assistance apparatus 1 is configured to assist the transporter 100 in transporting the bed 10 with the thrust applied as described above by operating the first and second motors 22R and 22L based on the detection signals of the sensors SW1 to SW5.

[0086]

To achieve such assistance, the controller 4 according to the present embodiment determines a direction in which the external force acts (hereinafter, also simply referred to as an “acting direction”) based on the detection signals of the sensors SW1 to SW5, and operates the first and second motors 22R and 22L to exert a thrust in the acting direction.

[0087]

For example, when the headboard 11h is pushed from the rear side toward the front side and it is determined that an external force is acting from the rear side toward the front side, the controller 4 rotates both the first and second motors 21R and 21L forward to rotate both the first and second mecanum wheels 22R and 22L forward. This can assist the forward movement of the bed 10 as illustrated in the upper left part of FIG. 7.

[0088]

The first and second mecanum wheels 21R and 21L are allowed to rotate forward and rearward when the corresponding motors 22R and 22L are not driven. This can reduce wobbling of the bed 10 being moved by hand, stabilizing the transport of the bed 10.

[0089]

The assistance by the controller 4 will be described in detail below with reference to FIG. 9 and some other drawings.

[0090]

FIG. 9 is a flowchart of a major process performed by the controller 4. FIG. 10 is a

flowchart of a process related to the determination of a moving direction. FIG. 11 is a control block diagram schematically illustrating compliance control. FIG. 12 is a conceptual diagram illustrating a basic concept of the compliance control. FIG. 13 is a graph of variation of velocity increase with respect to rotational speed. FIG. 14 is a graph of commanded rotational speed obtained by velocity increase control. FIG. 15 is a flowchart of the compliance control and the velocity increase control.

[0091]

FIG. 16 is a flowchart of control related to turning a corner. FIG. 17 is a view illustrating a trajectory of the bed 10 when turning a corner. FIG. 18 is a flowchart illustrating safety limit control.

[0092]

First, in Step S1 of FIG. 9, the controller 4 reads the detection signals of the five sensors SW1 to SW5 described above.

[0093]

In the subsequent Step S2, the controller 4 individually estimates the accelerations of the first and second mecanum wheels 21R and 21L based on the detection signals of the first and second current sensors SW1 and SW2.

[0094]

Hereinafter, the acceleration of the first mecanum wheel 21R is referred to as a “first acceleration,” and the acceleration of the second mecanum wheel 21L is referred to as a “second acceleration.” Both the first and second accelerations are time derivatives of translational velocity, that is, so-called tangential accelerations.

[0095]

The magnitude of the induced current detected by each of the first and second current sensors SW1 and SW2 is proportional to the torque acting on the first and second mecanum

wheels 21R and 21L (particularly, the torque caused by the reactive force) during the rotation of the wheels. The controller 4 individually estimates first torque acting on the first mecanum wheel 21R and second torque acting on the second mecanum wheel 21L based on the proportional relationship. At this time, a factor of proportionality for converting the induced current to the torque stored in the controller 4 in advance may be used.

[0096]

The controller 4 according to the present embodiment assists the movement of the bed 10 by driving the first and second motors 22R and 22L against the reactive forces corresponding to the first and second torques.

10 [0097]

To achieve such assistance, the controller 4 estimates the first acceleration corresponding to the first torque and the second acceleration corresponding to the second torque based on the following expressions (1) and (2).

[0098]

15
$$a_r = (-1) \cdot T_r / (R \cdot m) \cdots (1)$$

$$a_l = (-1) \cdot T_l / (R \cdot m) \cdots (2)$$

In the above expressions (1) and (2), T_r [Nm] is the first torque, and T_l [Nm] is the second torque. Further, a_r [m/s²] is the first acceleration corresponding to the first torque, and a_l [m/s²] is the second acceleration corresponding to the second torque.

20 [0099]

R [m] is the tire radius of each of the first and second mecanum wheels 21R and 21L, and m [kg] is the mass of each of the first and second mecanum wheels 21R and 21L. The first and second mecanum wheels 21R and 21L of the present embodiment have the same tire radius and mass.

25 [0100]

In the subsequent Step S3, the controller 4 estimates translational accelerations of the first and second mecanum wheels 21R and 21L based on the detection signals of the first and second current sensors SW1 and SW2.

[0101]

5 Specifically, the controller 4 estimates a longitudinal acceleration indicating the translational acceleration of the first and second mecanum wheels 21R and 21L in the front-rear direction and a lateral acceleration indicating the translational acceleration of the first and second mecanum wheels 21R and 21L in the lateral direction, respectively, using the first and second accelerations a_r and a_l estimated based on the detection signals of the first and second
10 current sensors SW1 and SW2.

[0102]

Specifically, when the first and second mecanum wheels 21R and 21L are configured as shown in FIGS. 3 to 5, the controller 4 estimates the longitudinal acceleration by adding the first acceleration a_r and the second acceleration a_l , and estimates the lateral acceleration by
15 calculating a difference between the first acceleration a_r and the second acceleration a_l . The following expressions (3) and (4) show the details of these operations.

[0103]

$$a_x = (a_r + a_l) / 2 \cdots (3)$$

$$a_y = (a_r - a_l) / 2 \cdots (4)$$

20 In the above expressions (3) and (4), a_x [m/s²] is the longitudinal acceleration, and a_y [m/s²] is the lateral acceleration. The left side of the expression (3) is defined as positive and the right side is defined as negative. The positive and negative signs may be reversed between the left and right sides. Similarly, the left side of the expression (4) is defined as positive and the right side is defined as negative. The positive and negative signs may be reversed between
25 the left and right sides.

[0104]

The relational expressions such as the expressions (3) and (4) are also satisfied for the rotational speeds of the first and second motors 22R and 22L (i.e., the rotational speeds of the first and second mecanum wheels 21R and 21L).

5 [0105]

Here, r_r [rpm] is the rotational speed of the first motor 22R in the front-rear direction (hereinafter also referred to as a “first rotational speed”), and r_l [rpm] is the rotational speed of the second motor 22L in the front-rear direction (hereinafter also referred to as a “second rotational speed”). Among these rotational speeds, the first rotational speed r_r is detected by the
10 first rotation sensor SW3, and the second rotational speed r_l is detected by the second rotation sensor SW4.

[0106]

Further, r_x [rpm] is the rotational speed of the first and second motors 22R and 22L as a whole in the front-rear direction (hereinafter, also referred to as a “longitudinal rotational
15 speed”), and r_y [rpm] is the rotational speed of the first and second motors 22R and 22L as a whole in the left-right direction (hereinafter, also referred to as a “lateral rotational speed”). When the first and second mecanum wheels 21R and 21L are configured and arranged as in the present embodiment, the following expressions (5) and (6) are satisfied.

[0107]

20
$$r_x = (r_r + r_l) / 2 \cdots (5)$$

$$r_y = (r_r - r_l) / 2 \cdots (6)$$

The expressions (5) and (6) can be modified to the following expressions (7) and (8). As shown in the expressions (7) and (8), r_r and r_l can be uniquely determined by setting r_x and
 r_y .

25 [0108]

$$r_r = r_x + r_y \cdot \cdot \cdot (7)$$

$$r_l = r_x - r_y \cdot \cdot \cdot (8)$$

A similar relational expression can be obtained for the velocity by multiplying both sides of each of the expressions (7) and (8) by a constant ($= \pi R/30$) dependent on the tire radius R and the circular constant. That is, v_r [m/s] is the velocity of the first mecanum wheel 21R in the front-rear direction, and v_l [m/s] is the velocity of the second mecanum wheel 21L in the front-rear direction. Further, v_x [m/s] is the velocity of the first and second mecanum wheels 21R and 21L as a whole in the front-rear direction (hereinafter, also referred to as a “longitudinal velocity”), and v_y [m/s] is the velocity of the first and second mecanum wheels 21R and 21L as a whole in the left-right direction (hereinafter, also referred to as a “lateral velocity”). When the first and second mecanum wheels 21R and 21L are configured and arranged as in the present embodiment, the following expressions (9) and (10) are satisfied.

[0109]

The “velocity” in this case indicates a translational velocity (tangential velocity) of an object in angular motion.

[0110]

$$v_x = (v_r + v_l) / 2 \cdot \cdot \cdot (9)$$

$$v_y = (v_r - v_l) / 2 \cdot \cdot \cdot (10)$$

The expressions (9) and (10) can be modified to the following expressions (11) and (12). As shown in the expressions (11) and (12), v_r and v_l can be uniquely determined by setting v_x and v_y .

[0111]

$$v_r = v_x + v_y \cdot \cdot \cdot (11)$$

$$v_l = v_x - v_y \cdot \cdot \cdot (12)$$

Further, by using the relationship between the expressions, for example, when the

command value of the longitudinal velocity v_x and/or the command value of the lateral velocity v_y is/are determined, the longitudinal rotational speed r_r and the lateral rotational speed r_l required to reach the command values can be uniquely determined, or the first rotational speed r_r and the second rotational speed r_l corresponding to the longitudinal rotational speed r_r and/or
5 the lateral rotational speed r_l can be determined.

[0112]

Subsequently, the controller 4 permits the driving of the first and second mecanum wheels 21R and 21L on condition that the rotational speeds of the first and second mecanum wheels 21R and 21L are equal to or higher than a predetermined value (first threshold) based
10 on the detection signals of the first and second rotation sensors SW3 and SW4.

[0113]

In particular, in Step S4 following Step S3, the controller 4 determines whether either one of the following relational expressions (13) and (14) is satisfied. Whether the bed 10 is actually being transported (whether the bed 10 is actually moving) can be checked by this
15 determination.

[0114]

$$r_x \geq T1 \cdots (13)$$

$$r_y \geq T1 \cdots (14)$$

In the expressions (13) and (14), $T1$ [1/s] is a first threshold. The magnitude of the first
20 threshold is stored in advance in the memory of the controller 4, and is set to be equal in the expressions (13) and (14). As described above, " r_x / r_y " in Step S4 of FIG. 9 means "either one of r_x or r_y " rather than "a quotient of r_x by r_y ."

[0115]

If both of the expressions (13) and (14) are not satisfied, the controller 4 determines
25 that the bed 10 is not being transported, and does not allow the driving of the first and second

motors 22R and 22L (Step S4: NO). In this case, the control process proceeds to Step S5. In Step S5, the controller 4 sets the commanded rotational speeds of the first and second motors 22R and 22L to zero.

[0116]

5 When the process proceeds to Step S5, the commanded rotational speeds of the first and second motors 22R and 22L (more specifically, assist velocities described later) are maintained at zero in the subsequent Steps S7 to S9 (details of Steps S7 to S9 will be described later). In this case, the controller 4 ends the flow shown in FIG. 9 without driving the first and second motors 22R and 22L.

10 [0117]

 If at least one of the expressions (13) and (14) is satisfied, the controller 4 determines that the bed 10 is actually being transported by an external force, and permits the driving of each of the first and second motors 22R and 22L (Step S4: YES). In this case, the control process proceeds to Step S6. In Step S6, the controller 4 commands the respective rotational speeds (assist rotational speeds) of the first and second motors 22R and 22L to assist the hand-propelled movement by the external force. The assist rotational speeds correspond to the command values of the longitudinal rotational speed r_x and the lateral rotational speed r_y .

[0118]

 Steps S11 to S15 in FIG. 10 illustrate the process executed in Step S6 of FIG. 9. That is, when the control process proceeds to Step S6, the controller 4 starts Step S11 of FIG. 10.

[0119]

 In Step S11, the controller 4 determines the moving direction of the bed 10 based on the longitudinal acceleration a_x and the lateral acceleration a_y estimated in Step S3 of FIG. 9. Specifically, the controller 4 according to the present embodiment determines whether the moving direction of the bed 10 is the front-rear direction (whether the bed 10 is moving forward

25 moving direction of the bed 10 is the front-rear direction (whether the bed 10 is moving forward

or rearward) or the left-right direction based on the longitudinal acceleration a_x and the lateral acceleration a_y .

[0120]

More specifically, in Step S11, the controller 4 determines whether the following
5 relational expression (15) is satisfied.

[0121]

$$|a_y| < T2 \cdots (15)$$

In the expression (15), $T2 [m/s^2]$ is a second threshold. The magnitude of the second threshold is stored in advance in the memory of the controller 4, and is suitably read out when
10 necessary.

[0122]

If the above expression (15) is not satisfied, the controller 4 determines that the moving direction of the bed 10 is the left-right direction, and advances the control process to Step S12 (Step S11: NO). Details of the process of Step S12 will be described later.

15 [0123]

If the above expression (15) is satisfied, the controller 4 determines that the moving direction of the bed 10 is the front-rear direction, and advances the control process to Step S13 (Step S11: YES).

[0124]

20 In Step S13, the controller 4 determines whether the bed 10 is turning about the z-axis shown in FIG. 8 based on the detection signal of the six-axis sensor SW5. Specifically, in Step S13, the controller 4 determines whether the following relational expression (16) is satisfied.

[0125]

$$|a_\psi| \geq T3 \cdots (16)$$

25 In the expression (16), $a_\psi [1/s^2]$ is the angular acceleration of the yaw angle, and $T3$

[1/s²] is a third threshold. The magnitude of the third threshold is stored in advance in the memory of the controller 4, and is suitably read out when necessary.

[0126]

If the above expression (16) is not satisfied, the controller 4 determines that the bed 10 is in no rotation (not turning), and advances the control process to Step S14.

[0127]

The process proceeds to Step S14 if it is determined that the bed 10 is moving forward or rearward without turning. In this case, the controller 4 performs the subsequent steps to perform both the compliance control which is the first control and the velocity increase control which is the second control based on the longitudinal acceleration a_x and the lateral acceleration a_y obtained by the first and second current sensors SW1 and SW2.

[0128]

If the above expression (16) is satisfied, the controller 4 determines that the bed 10 is making a turn (turning), and advances the control process to Step S15.

[0129]

The process proceeds to Step S15 if it is determined that the bed 10 is turning while moving forward or rearward (i.e., the bed 10 is turning a corner). In this case, the controller 4 performs control optimized for the turning, that is, control for assisting the hand-propelled movement of the bed in both the front-rear direction and the left-right direction.

[0130]

The process performed in Steps S12 and S14 and the process performed in Step S15 will be described in order. When the process proceeds to these steps, the controller 4 drives the first and second mecanum wheels 21R and 21L via the first and second motors 22R and 22L to assist the movement of the bed 10 in the moving direction determined in Step S11. In the course of the control, the controller 4 according to the present embodiment performs the compliance

control as the first control and the velocity increase control as the second control.

[0131]

The compliance control is performed by the controller 4 based on the acceleration estimated in Step S3 (i.e., at least one of the longitudinal acceleration a_x or the lateral acceleration a_y). For the compliance control, the controller 4 sets a velocity command in the front-rear direction or the left-right direction, that is, command values of the longitudinal velocity v_x and the lateral velocity v_y to follow the hand-propelled movement of the bed 10.

[0132]

As described with reference to the expressions (9) to (12), the command values of the first rotational speed r_r and the second rotational speed r_l are uniquely determined by setting the command values of the longitudinal velocity v_x and the lateral velocity v_y .

[0133]

The command value of the longitudinal velocity v_x and the command value of the lateral velocity v_y are respectively referred to as a longitudinal velocity command V_x and a lateral velocity command V_y . The command value of the first rotational speed r_r and the command value of the second rotational speed r_l of the motors 22R and 22L are respectively referred to as a first commanded rotational speed R_r and a second commanded rotational speed R_l .

[0134]

Setting the longitudinal velocity command V_x and the lateral velocity command V_y by the compliance control as in the present embodiment is equivalent to setting the first commanded rotational speed R_r and the second commanded rotational speed R_l to follow the movement of the bed 10.

[0135]

The velocity increase control is performed by the controller 4 based on the

accelerations estimated in Step S3 and the commanded rotational speeds set by the compliance control. In the velocity increase control, when the absolute values of the accelerations referred to for the compliance control are equal to or greater than a predetermined value (a fourth threshold T4 described later), the controller 4 increases the longitudinal velocity command V_x and the lateral velocity command V_y (in particular, the absolute values of the respective velocity commands V_x and V_y) set by the compliance control.

[0136]

Increasing the longitudinal velocity command V_x and the lateral velocity command V_y by the velocity increase control as in the present embodiment is equivalent to increasing the first commanded rotational speed R_r and the second commanded rotational speed R_l (in particular, the absolute values of the commanded rotational speeds R_r and R_l).

[0137]

First, a case where the control process proceeds to Step S12 or S14 will be described. Here, Steps S31 to S36 shown in FIG. 15 are the processes performed in Step S12 or S14 shown in FIG. 10. That is, when the control process proceeds to Step S12 or S14, the controller 4 performs each step in order from Step S31 of FIG. 15.

[0138]

For example, if the process proceeds from Step S12 to the flow of FIG. 15, that is, when it is determined that “the moving direction = the left-right direction,” the controller 4 performs the compliance control based on the lateral acceleration a_y , and performs the velocity increase control based on the lateral velocity command V_y obtained by the compliance control.

[0139]

If the process proceeds from Step S14 to the flow of FIG. 15, that is, when it is determined that “the moving direction = the front-rear direction,” the controller 4 performs the compliance control based on the longitudinal acceleration a_x , and performs the velocity increase

control based on the longitudinal velocity command V_x obtained by the compliance control.

[0140]

Then, a case where the process proceeds from Step S14 to the flow of FIG. 15 will be described in detail. In the flow of FIG. 15, Step S31 is related to the compliance control, and
5 Steps S32 to S34 are related to the velocity increase control.

[0141]

First, in Step S31, the controller 4 inputs the longitudinal acceleration a_x to the control block illustrated in FIG. 11 to calculate a command value of the longitudinal velocity v_x . The longitudinal acceleration a_x to be inputted is estimated based on the detection signals of the first
10 and second current sensors SW1 and SW2, and corresponds to an estimated value (actual measurement) of the longitudinal acceleration a_x .

[0142]

In this control block, s represents a Laplace operator, and M represents the inertia of the bed 10 and the transport assistance apparatus 1. D represents a damping coefficient between
15 a position of the bed 10 supported by the transporter 100 (e.g., the headboard 11h) and the first and second mecanum wheels 21R and 21L, and K represents a spring constant between the supported position and the first and second mecanum wheels 21R and 21L. The values of M , D and K are preset and stored in the controller 4.

[0143]

20 Suppose that the transport assistance apparatus 1, the bed 10, and the transporter 100 are rigid bodies, the longitudinal velocity v_x generated when the first and second mecanum wheels 21R and 21L rotate due to the application of the external force changes in synchronization with the moving speed of the bed 10 and the transporter 100 in the front-rear direction, and their magnitudes also coincide with each other. In this case, the longitudinal
25 velocity command V_x that follows the hand-propelled movement of the bed 10 is obtained by

integrating the actual measurement of the longitudinal acceleration a_x over time.

[0144]

In reality, however, components such as the frame 12 of the bed 10 and the fixture 7 of the transport assistance apparatus 1 are present between the supported position of the bed 10 and the first and second mecanum wheels 21R and 21L. Due to the deflection of the frame 12 or any other factor, the actual longitudinal velocity v_x may change with a delay from the moving speed of the bed 10 and the transporter 100, or may deviate from the moving speed.

[0145]

The control block illustrated in FIG. 11 is a model of the influence of the delay and the deviation. This control block shows the compliance control in which physical quantities corresponding to the force (longitudinal acceleration a_x and lateral acceleration a_y) are inputted and velocity commands (longitudinal velocity command V_x and lateral velocity command V_y) are outputted.

[0146]

In FIG. 11, first, the actual measurement of the longitudinal acceleration a_x is inputted to a first block B1 after passing through a subtractor P2. In this first block, the actual measurement of the longitudinal acceleration a_x is integrated over time. The output of the first block B1 indicates a correction amount ΔV of the longitudinal velocity command V_x (correction amount of the velocity command value) corresponding to the magnitude of the longitudinal acceleration a_x . The controller 4 sets the longitudinal velocity command V_x by adding or integrating the correction amount ΔV to the current longitudinal velocity command V_x .

[0147]

The output from the block B1 is multiplied by D/M in a second block B2, and then inputted to the subtractor P2 via an adder P1. The product inputted to the subtractor P2 is subtracted from the actual measurement of the longitudinal acceleration a_x . This feedback is

performed to take the damping proportional to the longitudinal velocity command V_x (particularly, the damping between the supported position of the bed 10 and the first and second mecanum wheels 21R and 21L).

[0148]

5 The output from the block B1 is also inputted to a third block B3. In the third block B3, the correction amount ΔV is further integrated over time. The output of the third block B3 is multiplied by K/M in a fourth block B4, and then inputted to the subtractor P2 via the adder P1. The product inputted to the subtractor P2 is subtracted from the actual measurement of the longitudinal acceleration a_x , similarly to the product obtained via the second block B2. This
10 feedback is performed to take a restoring force proportional to the amount of displacement (particularly, a restoring force due to deflection between the supported position of the bed 10 and the first and second mecanum wheels 21R and 21L).

[0149]

 By reflecting the two types of feedback on the longitudinal acceleration a_x , the
15 acceleration of the bed 10 (particularly, the acceleration at the position supported by the transporter 100) in consideration of the deflection and the damping is estimated. The acceleration integrated over time in the first block B1 is a velocity that follows the movement of the bed 10.

[0150]

20 In addition, a signal process for compensating for a time lag due to the feedback (e.g., a process using a delay operator) may be performed in the path from the adder P1 to the subtractor P2.

[0151]

 For example, as shown in the upper part of FIG. 12, when the transport assistance
25 apparatus 1, the bed 10, and the transporter 100 are moving at a constant speed, the acceleration

estimated by the first and second current sensors SW1 and SW2 is zero. In this case, the longitudinal acceleration a_x inputted to the control block of FIG. 10 is zero, and the correction amount ΔV outputted from the control block is also zero. In this case, the transport assistance apparatus 1 does not accelerate or decelerate.

5 [0152]

When the transporter 100 is moving faster than the transport assistance apparatus 1 as shown in the middle part of FIG. 12, the acceleration estimated by the first and second current sensors SW1 and SW2 is positive. In this case, an external force that pushes the bed 10 forward is applied to the bed 10 (see an arrow F1). Thus, the longitudinal acceleration a_x inputted to the control block of FIG. 10 is positive, and the correction amount ΔV outputted from the control block is also positive. At this time, the restoring force in the fourth block B4 acts in a direction that increases the correction amount ΔV (see an arrow F3). The transport assistance apparatus 1 accelerates with a delay from the application of the external force to move at the same speed as the bed 10 and the transporter 100.

15 [0153]

When the transporter 100 is moving with a delay from the transport assistance apparatus 1 as shown in the lower part of FIG. 12, the acceleration estimated by the first and second current sensors SW1 and SW2 is negative. In this case, an external force that pulls the bed 10 is applied to the bed 10 (see an arrow F2). Thus, the longitudinal acceleration a_x inputted to the control block of FIG. 10 is negative, and the correction amount ΔV outputted from the control block is also negative. At this time, the restoring force of the fourth block B4 acts in a direction that decreases the correction amount ΔV (see an arrow F4). The transport assistance apparatus 1 decelerates with a delay from the application of the external force to move at the same speed as the bed 10 and the transporter 100.

25 [0154]

In the subsequent Steps S32 to S34, the controller 4 performs the above-described velocity increase control. When performing the velocity increase control, the controller 4 increases the velocity command value with the increase in rotational speed detected by the first and second rotation sensors SW3 and SW4 (see FIG. 13). The horizontal axis in FIG. 13 does not mean the value obtained by dividing the longitudinal velocity by the lateral velocity. The graph shown in FIG. 13 means that the velocity command value in the front-rear direction (longitudinal direction) is set to increase with the increase in longitudinal velocity v_x , and the velocity command value in the left-right direction (lateral direction) is set to increase with the increase in lateral velocity v_y .

10 [0155]

Specifically, in Step S32, the controller 4 sets the velocity increase amount v_{off} so that it increases as the longitudinal velocity v_x increases. The velocity increase amount v_{off} may be set to increase with the increase in the longitudinal rotational speed r_x instead of the longitudinal velocity v_x .

15 [0156]

When the process proceeds from Step S12 to the flow of FIG. 15, the lateral velocity v_y is the determination target instead of the longitudinal velocity v_x . As described above, the controller 4 sets the velocity increase amount v_{off} so that it increases as the lateral velocity v_y increases. That is, the controller 4 sets the velocity increase amount v_{off} based on the moving direction determined in Step S11 of FIG. 10.

[0157]

In the subsequent Step S33, the controller 4 determines whether the following relational expression (17) is satisfied. In Step S33, it is determined whether the absolute value of the longitudinal acceleration a_x is equal to or greater than a predetermined value. This determination allows detection of whether the bed 10 is being pushed in the moving direction

25

(detection of a pushing force).

[0158]

$$|a_x| \geq T4 \cdots (17)$$

In the expression (17), T4 [m/s²] is a fourth threshold (predetermined value). The
5 magnitude of the fourth threshold T4 as the predetermined value is stored in advance in the
memory of the controller 4, and is suitably read out when necessary.

[0159]

When the process proceeds from Step S12 to the flow of FIG. 15, the lateral
acceleration a_y is compared instead of the longitudinal acceleration a_x . That is, the controller 4
10 determines whether the acceleration in the moving direction determined in Step S11 in FIG. 10
is equal to or greater than the fourth threshold T4.

[0160]

If the above expression (17) is satisfied (i.e., when the absolute value of the
longitudinal acceleration a_x is equal to or greater than the predetermined value), the controller
15 4 determines that the bed 10 is being pushed, and advances the control process to Step S34
(Step S33: YES).

[0161]

In Step S34, the controller 4 adds the velocity increase amount v_{off} to the velocity
command calculated in Step S31 (longitudinal velocity command V_x). The controller 4 sets the
20 obtained added value as a final velocity command (assist velocity) (Step S36). The assist
velocity in the front-rear direction is the above-described longitudinal velocity command V_x .
The assist velocity in the left-right direction is the above-described lateral velocity command
 V_y .

[0162]

25 Instead of calculating the velocity increase amount v_{off} and adding it to the velocity

command, an increase magnification (>1) that increases as the rotational speeds detected by the first and second rotation sensors SW3 and SW4 increase may be calculated, and the velocity command may be multiplied by the increase magnification to perform the velocity increase control.

5 [0163]

If the above expression (17) is not satisfied (i.e., when the absolute value of the longitudinal acceleration a_x falls below the predetermined value), the controller 4 determines that the bed 10 is not being pushed, and advances the control process to Step S35 (Step S33: NO).

10 [0164]

In Step S35, the controller 4 performs third control of reducing the velocity command after the second control.

[0165]

In particular, in Step S35, the controller 4 subtracts Δv_2 from the velocity increase amount v_{off} at that time, and advances the control process to Step S34. The subtraction amount Δv_2 of the velocity increase amount v_{off} may be constant. If the subtraction amount Δv_2 is set to be constant, and a state in which the bed 10 is not pushed continues, the velocity increase amount v_{off} gradually decreases. The velocity increase amount v_{off} is configured not to be less than zero in the subtraction. This ensures the assist velocity that follows the movement of the bed 10.

20 [0166]

For example, when the process proceeds from Step S33 to Step S34 in the n -th loop, the longitudinal velocity command V_x increases by the velocity increase amount v_{off} corresponding to the longitudinal velocity v_x . Thereafter, when the process proceeds from Step S33 to Step S35 in the $(n + 1)$ -th loop, the velocity increase amount v_{off} is subtracted from the

value at the time of the n-th loop. Then, when the flow from Step S33 to Step S35 is repeated, the longitudinal velocity command V_x decreases to the value calculated in Step S31.

[0167]

FIG. 14 is a graph of comparison between the assist rotational speed (broken line) when the compliance control is performed without the velocity increase control and the assist rotational speed (solid line) when both the compliance control and the velocity increase control are performed. Each circle in FIG. 14 indicates timing when it is determined that the bed 10 is pushed (when YES is selected at Step S33).

[0168]

When the compliance control alone is performed, the assist rotational speed rises with a delay from the movement of the bed 10, and then hovers at a value that follows the movement.

[0169]

When both the compliance control and the velocity increase control are performed, the assist rotational speed rises steeply every time it is determined that the bed 10 is pushed (e.g., see $t = t_1, t_2, t_3$). If a period in which it is determined that the bed 10 is not pushed continues, the assist rotational speed after the rise gradually decreases with time (e.g., see $t_1 < t < t_2$ and $t_2 < t < t_3$).

[0170]

More specifically, in FIG. 14, a period from when the assist rotational speed (assist velocity) determined by the compliance control starts to increase to when it starts to decrease (a period from when the broken line increases to when it starts to decrease) corresponds to “when the bed is pushed” as indicated by B in FIG. 12. In this case, YES is appropriately selected at Step S33, and the velocity increase amount v_{off} is set to be nonzero and positive each time. For example, when the bed 10 is pushed relatively strongly (when the bed 10 is pushed so strongly that YES is selected in the determination in Step S33), the assist rotational speed

risers steeply as described above. When the bed 10 is pushed relatively gently (when the bed 10 is pushed to the extent that YES is not selected in the determination in Step S33), the assist rotational speed (assist velocity) gradually decreases to a value that follows the movement of the bed 10.

5 [0171]

In FIG. 14, a period from when the assist rotational speed (assist velocity) determined by the compliance control starts to decrease (a period from when the broken line turns to decrease to when it reaches zero) corresponds to “when the bed is pulled” as indicated by C in FIG. 12. In this case, YES is not selected in the determination at Step S33, and the velocity
10 increase amount v_{off} remains at its lower limit (zero). As a result, the assist rotational speed (assist velocity) decreases to zero while being maintained at a value determined by the compliance control.

[0172]

Then, when the process of Step S36 is completed, the control process ends the flows
15 of FIGS. 10 and 15, and proceeds to Step S7 of FIG. 9.

[0173]

The description with reference to FIG. 15 also applies to the case where the process proceeds from Step S12 to the flow of FIG. 15. In this case, the term “longitudinal” in the above description may be replaced with the term “lateral,” and the term “front-rear” with the term
20 “left-right.” The same applies to the mathematical expressions. In this case, the predetermined values such as the fourth threshold T4 may be the same or may be different in the front-rear direction and the left-right direction.

[0174]

If the process proceeds from Step S13 to Step S15, the controller 4 sets the assist
25 rotational speeds in both the longitudinal and lateral directions to assist the bed 10 in turning

the corner.

[0175]

Steps S41 to S44 in FIG. 16 are the processes performed in Step S15 of FIG. 10. That is, when the control process proceeds to Step S15, the controller 4 performs each step in order from Step S41 of FIG. 15.

[0176]

First, in Step S41, the controller 4 adjusts the lateral acceleration a_y estimated in Step S3 of FIG. 9 so that the lateral acceleration a_y decreases at a predetermined ratio exceeding zero. Specifically, the controller 4 maintains the value of the longitudinal acceleration a_x estimated in Step S3, and converts the lateral acceleration a_y as shown in the following expression (18).

[0177]

$$a_y' = c_y * a_y \cdots (18)$$

In the above expression (18), c_y representing the predetermined ratio is set in advance according to the dimensions, weights, and configurations of the bed 10 and the transport assistance apparatus 1, and is stored in the controller 4. The predetermined ratio c_y is specifically set to be less than 1 ($0 < c_y < 1$), more specifically, less than 0.5 ($0 < c_y < 0.5$).

[0178]

The predetermined ratio c_y is set to shift the turning center O_t of the bed 10 from the center position P_c between the first and second mecanum wheels 21R and 21L to the front end of the bed 10 (see FIG. 17).

[0179]

As shown in FIG. 4, the center position P_c referred to herein may be a center position between the first and second mecanum wheels 21R and 21L in the left-right direction, and may be a position intersecting the first and second rotation axes O_{y1} and O_{y2} in the front-rear direction.

[0180]

In the subsequent Step S42, the controller 4 performs the compliance control as the first control for the front-rear direction based on the longitudinal acceleration a_x estimated in Step S3.

5 [0181]

In particular, the controller 4 according to the present embodiment performs both the compliance control and the velocity increase control as the second control in order for the front-rear direction based on the longitudinal acceleration a_x estimated in Step S3. Details of the compliance control and the velocity increase control for the front-rear direction are as described
10 with reference to FIG. 15. By performing Step S42, the controller 4 sets the velocity command in the front-rear direction as described above.

[0182]

That is, for the front-rear direction, the velocity commands (and the commanded rotational speeds of the first and second motors 22R and 22L) to follow the front-rear movement
15 of the bed 10 are calculated, and then the control is performed to raise the velocity commands (commanded rotational speeds) in synchronization with the push of the bed 10.

[0183]

In the subsequent Step S43, the controller 4 performs the compliance control as the first control for the left-right direction (lateral direction) based on the lateral acceleration a_y'
20 adjusted in Step S41.

[0184]

In particular, the controller 4 according to the present embodiment performs the compliance control based on the adjusted lateral acceleration a_y' for the lateral direction without performing the velocity increase control as the second control. In this case, the controller 4
25 performs the process other than Steps S32 to Step S35 in FIG. 15, and sets the velocity

command in the left-right direction.

[0185]

That is, for the left-right direction, although the control of calculating the velocity commands (and the commanded rotational speeds of the first and second motors 22R and 22L) that slightly follow the lateral movement of the bed 10 is performed, the control of raising the velocity commands (commanded rotational speed) in synchronization with the push of the bed 10 is intentionally not performed.

[0186]

In the subsequent Step S44, the controller 4 sets the velocity command set in Step S42 as the assist velocity in the front-rear direction, and sets the commanded rotational speed set in Step S43 as the assist velocity in the lateral direction.

[0187]

When the flow of Steps S12, S14, and S15 of FIG. 10 is completed, the control process proceeds to Step S7 of FIG. 9. In Step S7, the controller 4 converts the longitudinal velocity command V_x or the lateral velocity command V_y set as the assist rotational speed into the first commanded rotational speed R_r and the second commanded rotational speed R_l by the following expressions (19) and (20) determined in the same manner as the above expressions (5) and (6).

[0188]

$$R_r = 60 * (V_x + V_y) / (2\pi \cdot R) \cdots (19)$$

$$R_l = 60 * (V_x - V_y) / (2\pi \cdot R) \cdots (20)$$

In the above expressions (19) and (20), “R” represents the tire radius described above.

In the present embodiment, $V_x \neq 0$ and $V_y = 0$ are satisfied when assisting the movement in the front-rear direction, $V_x = 0$ and $V_y \neq 0$ are satisfied when assisting the movement in the left-right direction, and $V_x \neq 0$ and $V_y \neq 0$ are satisfied when assisting the turning the corner.

[0189]

For example, when the controller 4 determines that the bed 10 is moving in the front-rear direction (Step S14 is performed), the controller 4 sets the first and second commanded rotational speeds R_r and R_l to rotate both the first and second mecanum wheels 21R and 21L forward or rearward as illustrated in the upper left and upper right parts of FIG. 7. When setting
5 the commanded rotational speeds, the controller 4 makes the absolute values of the commanded rotational speeds of the first mecanum wheel 21R and the second mecanum wheel 21L equal to each other ($R_r = R_l$).

[0190]

Making the absolute values of the first and second commanded rotational speeds R_r
10 and R_l equal to each other can stabilize the movement in the front-rear direction regardless of the orientation of each caster 14.

[0191]

When the controller 4 determines that the bed 10 is moving in the left-right direction (Step S12 is performed), the controller 4 sets the first and second commanded rotational speeds
15 R_r and R_l so that one of the first and second mecanum wheels 21R and 21L rotates forward and the other rotates rearward as illustrated in the lower left part of FIG. 7. When setting the commanded rotational speeds, the controller 4 makes the absolute values of the commanded rotational speeds of the first mecanum wheel 21R and the second mecanum wheel 21L equal to each other ($R_r = -R_l$).

20 [0192]

When the controller 4 determines that the bed 10 is turning the corner (Step S12 is performed), the controller 4 sets the first and second commanded rotational speeds R_r and R_l so that at least one of the first and second mecanum wheels 21R and 21L rotates, as illustrated in the lower right part of FIG. 7. When setting the commanded rotational speeds, the absolute
25 values of the first mecanum wheel 21R and the second mecanum wheel 21L are set to be

different so that the turning center O_t is located at the position illustrated in FIG. 17 ($|R_r| \neq |R_l|$).

[0193]

Thereafter, in Step S8 following Step S7, the controller 4 performs the safe control process. Details of this process are as shown in Steps S51 and S52 in FIG. 18.

5 [0194]

First, in Step S51, the controller 4 determines whether the absolute values of the commanded rotational speeds R_r and R_l set through the flow of FIG. 9 are equal to or greater than a predetermined fifth threshold $T5$. The magnitude of the fifth threshold $T5$ is stored in advance in the memory of the controller 4, and is suitably read out as needed.

10 [0195]

If the determination at Step S51 is YES, the controller 4 advances the control process to Step S52. In Step S52, the controller 4 changes the commanded rotational speeds R_r and R_l to the fifth threshold $T5$.

[0196]

15 If NO is selected in the determination of Step S51, the controller 4 skips Step S52 and returns. In this case, the magnitudes of the commanded rotational speeds R_r and R_l are maintained to be less than the fifth threshold $T5$.

[0197]

As described above, the controller 4 according to the present embodiment is configured
20 to maintain the values of the first and second commanded rotational speeds R_r and R_l when the first and second commanded rotational speeds R_r and R_l are less than the predetermined threshold (fifth threshold $T5$) (Step S51: NO) after the velocity increase control as the second control is performed, and to change the first and second commanded rotational speeds R_r and R_l to the fifth threshold $T5$ when the first and second commanded rotational speeds R_r and R_l
25 are equal to or greater than the fifth threshold $T5$ (Step S51: YES).

[0198]

Then, in Step S9 following Step S8 in FIG. 9, the controller 4 drives the first and second mecanum wheels 21R and 21L via the first and second motors 22R and 22L to assist the movement of the bed 10 in the moving direction. At this time, the first and second motors 22R
5 and 22L are driven to reach the commanded rotational speeds R_r and R_l determined in Steps S5, S6, and S7.

[0199]

Thus, when the bed is pushed to move in the front-rear direction or the left-right direction, the first and second mecanum wheels 22R and 22L are driven via the first and second
10 motors 21R and 21L to assist the hand-propelled movement in the moving direction. When the bed 10 is turning while moving in the front-rear direction, that is, when the bed 10 is turning the corner, the first and second mecanum wheels 22R and 22L are driven via the first and second motors 21R and 21L to assist the hand-propelled movement in both the front-rear direction and the left-right direction.

15 [0200]

Accordingly, the bed 10 is allowed to turn while sliding in the lateral direction instead of turning around the center position P_c as in the case when only the movement in the front-rear direction is assisted. For example, when turning the bed 10 to the right as shown in FIG. 17, an external force that causes the bed 10 to slide to the left (in the opposite direction of the
20 turning direction) acts in addition to the external force pushing the bed 10 forward, and thus, feeding back and assisting the external force allows the bed to turn the corner while sliding (or drifting) leftward.

[0201]

As a result, as shown in FIG. 17, the bed 10 is allowed to turn about the turning center
25 O_t shifted to the front end of the bed 10, allowing the bed 10 to turn on the trajectory shown in

FIG. 17.

[0202]

If the assistance in the lateral direction is not provided, the bed moves along the trajectory that turns about the turning center O_t which is the center position P_c between the first and second mecanum wheels 21R and 21L as shown in the conventional example of FIG. 19. Such a trajectory has a small turning radius, and is disadvantageous because the bed 10 may interfere with the corner of the passage.

[0203]

Although not shown, when the bed turns left, an external force that slides the bed 10 to the right (in the opposite direction to the turning direction) acts in addition to the external force that pushes the bed 10 forward, and thus, feeding back and assisting the external force allows the bed 10 to turn while sliding to the right. In this case, the bed can follow a smooth trajectory as shown in FIG. 17.

[0204]

As described above, according to the present embodiment, the controller 4 assists the hand-propelled movement in the lateral direction in addition to the front-rear direction (see Steps S43 and S44 in FIG. 16). When the bed 10 turns the corner, it is considered that a force is also applied in the direction of the turning radius, that is, in the lateral direction of the bed. Thus, by assisting such a lateral force, the bed 10 can slide in the lateral direction when turning the corner. As a result, the turning radius increases, reducing the interference between the front or rear end of the bed 10 and the corner of the passage. This can suitably assist the bed 10 in turning the corner.

[0205]

Further, as illustrated in Steps S2 and S3 in FIG. 9, detecting the induced current allows estimating the torque that causes the induced current (the torque that causes the first and

mecanum wheels 21R and 21L to rotate), and thus, allows estimating the acceleration corresponding to the torque. The direction in which the external force acts can be estimated by estimating the acceleration of each of the mecanum wheels 21R and 21L.

[0206]

5 Then, while the assistance is provided in the front-rear direction to follow the hand-propelled movement, the acceleration in the lateral direction is reduced as shown in Step S41 in FIG. 16, and the compliance control is performed based on the reduced acceleration. Reducing the acceleration in the lateral direction is equivalent to estimating the external force acting in the same direction to be smaller than the external force actually acting. By estimating
10 the external force to be small, assistance in the lateral direction is given to the extent not to follow the hand-propelled movement. As a result, excessive sliding in the lateral direction (sliding more than intended by the transporter 100) can be reduced, and the turning radius can be kept within an appropriate range. This is advantageous in appropriately assisting the bed 10 in turning the corner.

15 [0207]

 As described with reference to FIG. 17, by shifting the turning center Ot of the bed 10 to the front end, the rear end of the bed can turn more than the front end when the bed 10 turns the corner. By greatly turning the rear end, interference between the rear end and the corner of the passage can be reduced. This is advantageous in appropriately assisting the bed 10 in turning
20 the corner.

[0208]

 Further, as shown in Step S42 in FIG. 16, the velocity increase control performed for the front-rear direction not only allows the wheels to simply follow the hand-propelled movement, but also reduces the load on the transporter 100 by the amount of increase in the
25 commanded rotational speeds. This makes it easier to push the bed 10 in the front-rear direction,

and can give the transporter 100 an appropriate “feeling of being assisted.” For the lateral direction, the velocity increase control is intentionally omitted as illustrated in Step S43 of FIG. 16. This can reduce excessive sliding in the lateral direction (sliding more than intended by the transporter 100), and can keep the turning radius within an appropriate range. This is advantageous in appropriately assisting the bed 10 in turning the corner.

[0209]

With the first and second mecanum wheels 21R and 21L configured and arranged as illustrated in FIGS. 3 to 5 and 7, a thrust that causes the bed 10 to turn can be exerted when the first mecanum wheel 21R and the second mecanum wheel 21L rotate in opposite directions.

This configuration is effective in appropriately assisting the bed 10 in turning the corner.

[0210]

For the movement in the front-rear direction, the absolute values of the commanded rotational speeds are made equal to each other, allowing more stable front-rear movement regardless of the orientation of the casters 14. When the bed turns the corner, the absolute values are intentionally made different from each other, allowing the bed to turn along a desired trajectory.

[0211]

<Other Embodiments>

In the above embodiment, the first and second current sensors SW1 and SW2 are used as the status sensors for determining whether the bed 10 is moving forward or rearward. However, the present disclosure is not limited to this configuration. For example, the first and second rotation sensors SW3 and SW4 may be used as the status sensors, or the six-axis sensor SW5 may be used as the status sensor.

[0212]

In the above embodiment, the velocity increase control is performed to increase the

velocity command (command value of the translational velocity), but this configuration is not essential.

[0213]

For example, in Steps S32 to S34, a process of increasing the commanded rotational speed may be performed instead of the process related to the velocity command. In this case, a process of converting the velocity command into the commanded rotational speed is performed between Steps S31 and S32.

DESCRIPTION OF REFERENCE CHARACTERS

10 [0214]

1 Transport Assistance Apparatus

4 Controller

10 Bed (Bed with Casters)

14 Caster

15 14F Front Caster

14B Rear Caster

21R First Mecanum Wheel

211R First Wheel Body (Wheel Body)

212R First Barrel-Shaped Roller (Barrel-Shaped Roller)

20 21L Second Mecanum Wheel

211L Second Wheel Body (Wheel Body)

212L Second Barrel-Shaped Roller (Barrel-Shaped Roller)

22R First Motor

22L Second Motor

25 cy Predetermined Ratio

	F	Transport Surface
	Ot	Turning Center
	Pc	Center Position
	Oy1	First Rotation Axis (Rotation Axis)
5	Oy2	Second Rotation Axis (Rotation Axis)
	Or	First Inclined Axis (Inclined Axis)
	Ol	Second Inclined Axis (Inclined Axis)
	SW1	First Current Sensor (Status Sensor)
	SW2	Second Current Sensor (Status Sensor)
10	SW5	Six-Axis Sensor (Turning Sensor)

CLAIMS

[Claim 1] A transport assistance apparatus for assisting a hand-propelled movement of a bed with casters, the transport assistance apparatus comprising:

5 a first mecanum wheel and a second mecanum wheel that are attached to a lower portion of the bed and make contact with a transport surface on which the bed travels;

a first motor and a second motor that are respectively connected to the first mecanum wheel and the second mecanum wheel to drive the first mecanum wheel and the second mecanum wheel;

10 a status sensor that detects signals corresponding to rotation statuses of the first and second mecanum wheels;

a turning sensor that detects a turn of the bed about a rotation axis perpendicular to the transport surface; and

a controller that controls the first and second motors,

15 wherein

the controller determines whether the bed is moving forward or rearward and whether the bed is turning based on detection signals of the status sensor and the turning sensor, and the controller

drives the first and second mecanum wheels via the first and second motors
20 to assist the hand-propelled movement in a front-rear direction when it is determined that the bed is moving forward or rearward without turning, and

drives the first and second mecanum wheels via the first and second motors to assist the hand-propelled movement in both the front-rear direction and a lateral direction perpendicular to the front-rear direction and parallel to the transport surface when it is
25 determined that the bed is turning while moving forward or rearward.

[Claim 2] The transport assistance apparatus of claim 1, wherein
the status sensor includes a first current sensor that detects an induced current flowing
through the first motor when the first mecanum wheel rotates, and a second current sensor that
5 detects an induced current flowing through the second motor when the second mecanum wheel
rotates,
the controller
estimates a longitudinal acceleration indicating an acceleration of the first and
second mecanum wheels in the front-rear direction and a lateral acceleration indicating an
10 acceleration of the first and second mecanum wheels in the lateral direction based on the
detection signals of the first and second current sensors, and
performs first control of commanding rotational speeds of the first and second
motors based on at least one of the longitudinal acceleration or the lateral acceleration to follow
the hand-propelled movement, and
15 when it is determined that the bed is turning while moving forward or rearward, the
controller
performs the first control for the front-rear direction based on the longitudinal
acceleration, and
performs the first control for the lateral direction based on the lateral
20 acceleration after being adjusted to decrease by a predetermined ratio exceeding zero.

[Claim 3] The transport assistance apparatus of claim 2, wherein
the predetermined ratio is set so that a turning center of the bed is shifted from a center
position between the first and second mecanum wheels to a front end of the bed.

25

[Claim 4] The transport assistance apparatus of claim 2, wherein
when it is determined that the bed is moving forward or rearward without turning, the
controller performs the first control based on the longitudinal acceleration and second control
of increasing the commanded rotational speeds, and
5 when it is determined that the bed is turning while moving forward or rearward, the
controller
performs the first control and the second control in order for the front-rear
direction based on the longitudinal acceleration, and
performs the first control for the lateral direction based on the adjusted lateral
10 acceleration without performing the second control.

[Claim 5] The transport assistance apparatus of any one of claims 1 to 4,
wherein
the first and second mecanum wheels are arranged side by side in the lateral direction,
15 each of the first and second mecanum wheels includes
a wheel body that rotates about a rotation axis extending in the lateral
direction and
a plurality of barrel-shaped rollers arranged along an outer periphery of the
wheel body and rotating about an inclined axis inclined with respect to both the front-rear
20 direction and the lateral direction, and
the inclined axis of the first mecanum wheel is inclined to be line-symmetrical with
the inclined axis of the second mecanum wheel with respect to the front-rear direction.

[Claim 6] The transport assistance apparatus of claim 5, wherein
25 the controller

commands rotational speeds of the first and second mecanum wheels so that both the first and second mecanum wheels rotate forward or rearward when it is determined that the bed is moving forward or rearward without turning, and when commanding the rotational speeds, makes absolute values of the commanded rotational speeds of the first and
5 second mecanum wheels equal to each other, and

commands the rotational speeds so that the first mecanum wheel and the second mecanum wheel have different absolute values when it is determined that the bed is turning while moving forward or rearward.